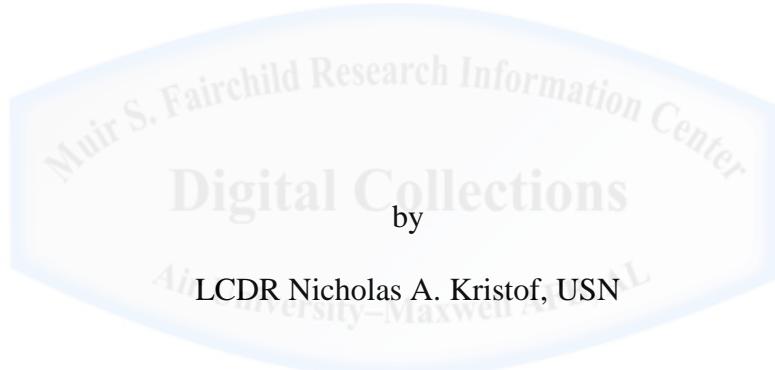


AU/ACSC/KRISTOF/AY11

AIR COMMAND AND STAFF COLLEGE
AIR UNIVERSITY

HYBRID AIRCRAFT FOR
HEAVY LIFT / HIGH SPEED STRATEGIC MOBILITY



A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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Preface

Nicholas Kristof is a graduate of the United States Naval Academy and a submariner. His decision to research the military utility of hybrid aircraft was based on a years-long curiosity with the subject. The Air Command and Staff College provided him with the first opportunity to pursue that curiosity.

He would like to thank several individuals for the generosity that they displayed to him through their time, opinions, expertise, the materials and information that they provided, and their willingness to answer questions, sometimes repeatedly. In no particular order, he would like to thank Mr. Phil Hunt, formerly of DARPA and now at the Worldwide Aeros Corporation, Mr. Michael McGuinness at EUCOM, Dr. Robert Boyd at Lockheed Martin, Mr. Steve Huett and Mr. Chuck Myers at NAVAIR, and Mr. Ed Sheedy at Northrop Grumman. This group of people represents or has ties to all of the major players in the development of hybrid aircraft, and this paper would be a lesser product were it not for their expert assistance.

Most importantly, he would like to his wife, Marcianne. Her ability to put up with the torturous research and writing schedule that this effort required was truly heroic.

Abstract

US Transportation Command (USTRANSCOM) has at its disposal a wide range of vehicles to support its strategic lift requirements. Across this range of capabilities, there exists an operational “hole” characterized by heavy lift at high speed. Surface vessels, such as the LMSR and FSS, can be categorized as Heavy Lift / Low Speed (HL/LS) vehicles while aircraft, the C-17 and C-5, can be categorized as Light Lift / High Speed (LL/HS). This paper proposes that the US military procure a Heavy Lift / High Speed (HL/HS) Hybrid Aircraft transport, able to transport 15 C-17 loads of cargo (approximately 1300 tons of cargo) at a cruising speed of 115 knots. Such a vehicle would greatly improve USTRANSCOM’s ability to meet its mission objectives while expanding the geography into which cargo transport is possible.

Commencing with a brief history of lighter-than-air vehicles and a review of “airship basics,” this paper describes the operational advantages of hybrid aircraft, including the ability to provide direct “fort to fight” transport and debark combat-ready forces in austere locations while drastically reducing the cost per ton mile of material transported and other logistic burdens. A review of military studies and planning documents shows that these capabilities are widely understood to be vital to the military’s ability to conduct operations in the coming decades—bolstering the case for hybrid aircraft procurement. The paper concludes with a review of the technology hurdles, technical challenges, and other issues that may prevent their development and employment and recommendations for the Department of Defense in moving forward.

The ability of the US military to move massive amounts of cargo quickly and cheaply will affect its ability to conduct those missions assigned to it; a Heavy Lift, High Speed Hybrid Aircraft transport offers a revolutionary capability to accomplish this. The US military should invest in these technologies today.

Introduction

Current Strategic Lift

US Transportation Command (USTRANSCOM) has at its disposal a wide range of vehicles to support its strategic lift requirements. Each vehicle provides a certain cargo capability in terms of weight/volume, speed, and logistic requirements. Across this range of capabilities, there exists an operational “hole” characterized by heavy lift at high speed. Due to the nature of current capabilities, logistic needs are prohibitive to the types of operations projected to become more common in the 2035 time frame. This paper proposes that the US military procure a new class of vehicle to accomplish two major goals: 1) Fill the operational hole mentioned above in terms of weight and speed, and 2) Eliminate the logistic burdens inherent in current capability. The proposed vessel is a Heavy Lift / High Speed (HL/HS) Hybrid Aircraft (HA) transport, hereafter known as the *Blue Horizons Airlifter*; such a vehicle would greatly improve USTRANSCOM’s ability to meet its mission objectives while at the same time expanding the geography into which cargo transport is possible.

USTRANSCOM strategic lift capabilities are conducted by four classes of vehicles. The highest gross tonnage carrier is the Large Medium Speed Roll-On/Roll-Off (LMSR) vessel, which can travel at 24 knots and carries approximately 152 C-17 loads of cargo by weight or almost 320 C-17 loads of cargo by square footage. The next vessel is the Fast Sealift Ship (FSS), which transits at 30 knots and carries approximately 152 C-17 loads of cargo by square footage. The C-5 is next, travelling at 500 knots and able to carry 1.70 C-17 loads by weight or two C-17 loads by square footage. Last is the C-17 itself with a cruise speed of 450 knots.

The surface vessels can be categorized as Heavy Lift / Low Speed (HL/LS) vehicles while the aircraft can be categorized as Light Lift / High Speed (LL/HS). This division of labor

is effective and allows USTRANSCOM incredible flexibility in how it transports material around the world. However, this capability depends upon certain assumptions, namely the existence of accessible deep draft sea ports and airports with runways able to receive the C-5/C-17. If one assumes that the United States will find itself engaging in failed-state scenarios and humanitarian crises with increasing frequency in the coming decades, these logistic requirements will not be met. And while the current capability is flexible, it requires a prohibitive number of sorties to transport even a moderately sized force and their organic equipment.

A Future Capability

Greater relative flexibility could be achieved through the development and employment of a Heavy Lift / High Speed (HL/HS) transport, able to transport 15 C-17 loads of cargo (approximately 1300 tons of cargo) at a cruising speed of 115 knots. A Hybrid Aircraft (HA) with these capabilities could be designed and built today, serving as a viable HL/HS transport. The term *hybrid aircraft* denotes a class of vehicle that derives lift through two discrete mechanisms—buoyancy, like a balloon, and aerodynamic lift, like an airplane; its unique characteristics are particularly suited to the efficient airlift of heavy and oversized cargoes.

A HA able to land in austere locations, including on water, is not limited by sea- and airports, nor is the delivery of cargo limited by the infrastructure between that port and its eventual final destination. Poor or nonexistent transportation infrastructure would not prevent the delivery of goods or military forces. If the requirement for “suitable” sea- and airports is eliminated, the possible scope of mobility operations can be increased dramatically. While there are trade-offs to be made between maximum altitude and payload capacity that might affect the HA’s ability to fly over certain mountain ranges, all other geographic difficulties are eased.

A significant amount of design work has already been undertaken by industry at the request of the US military. These efforts must be continued and fostered in order to overcome the technological hurdles that remain to field this capability. These hurdles include advances in lightweight structural components, aerodynamic modeling to understand and optimize the flight characteristics of these vehicles, buoyancy control systems to ensure that the onload/offload of vast amounts of cargo does not adversely affect flight characteristics, avionics and flight control systems, and, for certain classes of HA, the large-scale manufacture of lightweight, high-strength fabrics for lifting envelopes as well as the fabrication processes used to construct them. None of these hurdles appear to be beyond the reach of existing technology to solve, however, it is their integration into a single platform and the need to re-discover airship design lessons learned that have been lost for decades that will challenge the engineers.

The HL/HS HA concept has been widely discussed and studied over the past decade. Several companies are in existence today solely to develop and exploit this capability. Well-known defense contractors are pursuing this technology, either through self-financed research or agreements with smaller players. The analytic challenges are mostly understood, and academia is making progress. Potential customers, ranging from US combatant commanders to non-governmental organizations, are aware of the concept and understand its implications to their achieving their aims. This paper recommends the eventual development of a HA with a cargo capacity of 1300 tons.

Research Question and Thesis

In conducting this research, the author will attempt to determine whether or not the *Blue Horizons Airlifter*, a HL/HS HA transport, is feasible for deployment in the 2035 time frame. Chapter One of this paper will provide a brief history of Lighter-than-Air aircraft focusing on the

development of HA. Chapter Two will discuss “airship basics” as the necessary groundwork for later discussions involving technology development and the nominal operating characteristics of these aircraft. Chapter Three will specifically discuss HA, describing the advantages and disadvantages inherent in their employment. Chapter Four will analyze the utility of a HL/HS HA transport in terms of past, current, and future warfighter needs. Chapter Five will describe the *Blue Horizons Airlifter* in greater detail, including technical and other challenges that may prevent its development and a listing of other possible mission areas that HA may be able to fulfill. The Conclusion will include a list of recommendations for the DOD.

I: A Very Brief History of Lighter-than-Air (LTA) Aircraft

Man first ascended into the air on balloons in the 1780s and, almost since that first instance of manned flight, theorists discussed the military uses of this technology. Balloons were used for mapping and reconnaissance during wars in the early 19th century, eventually used even to drop primitive bombs; they were used by Union forces during the American Civil War. In the early 20th century, Britain spearheaded research into the use of blimps—balloons that move under their own propulsion. Many nations followed this development and began to employ them in their militaries. Dirigibles, steerable airships including blimps although often taken to mean rigid airships, truly came into their own during the World War I and achieved their greatest American successes during that and the Second World War.

Early Modern Military Airship Operations

Dirigibles entered widespread military use during World War I. The United States and United Kingdom used them as escorts for shipping convoys; they are widely credited with helping to end the German submarine threat. During World War II, approximately 530 ships

without airship escorts were sunk near the US coast by enemy submarines; of the approximately 89,000 ships in convoys escorted by airship, only one, the tanker *Persephone*, was sunk by an enemy submarine.¹ Blimps remained in the US Navy's inventory until 1962 when, due to their technology failing to match conventional aircraft development, they were retired.

A History of Hybrid Aircraft

The first attempt to fly a HA was made by Alberto Santos-Dumont, a Brazilian living in France and a pioneer in the controlled flight of airships. In 1905, he attempted to fly his *Number 14*, an airship envelope combined with an airplane frame; unfortunately, it proved unworkable.² (See Figure 1) The first modern attempt to construct a HA dates to the late 1960's by the Aereon



Figure 1: Santos-Dumont's Number 14
(Source: Wikipedia.org at http://en.wikipedia.org/wiki/Hybrid_airship)

Corporation. A test vehicle, the *Aereon 26*, was flown in 1970 and 1971.³ The findings from those flights were that “the ‘aerobody’ is aerodynamically a feasible concept... The next step (and major milestone) will be the development of the Dynairship aerobody, operationally to prove the concept of adding aerostatic lift to this aerodynamically proven configuration.”⁴

The Chief Executive Officer of Aereon, William Miller, suggested the following regarding HA, the same issues that make the concept worth investigation today:

It would carry much more tonnage than the same-sized airship. ... The Dynairship would be more energy-conservative than typical transport airplanes, with a lower ton-miles per hour productivity, but less thrust horse-power will be required and large cube-capacity for low density cargoes or low-density fuels is available at no penalty to cargo space. ... In contrast to many airplanes, a hybrid aircraft offers a long-loiter capability at low fuel consumption while it could also have a top speed twice that of blimps. This combination is useful for patrol tasks, whether over cities or ocean spaces.⁵

Miller also postulated several Dynairships, including a small patrol aircraft, a medium sized cargo aircraft, and a 1000' long logistic carrier able to carry 3,300 tons of cargo.⁶ Modern analyses show his calculations to be optimistic, but his comments demonstrate that even 40 years ago, the potential for HA as strategic lift assets was recognized. Unfortunately, the Aereon Corporation was unable to secure further funding and folded not long after the flights of the *Aereon 26*. Figure 2 shows two photographs of the *Aereon 26*.

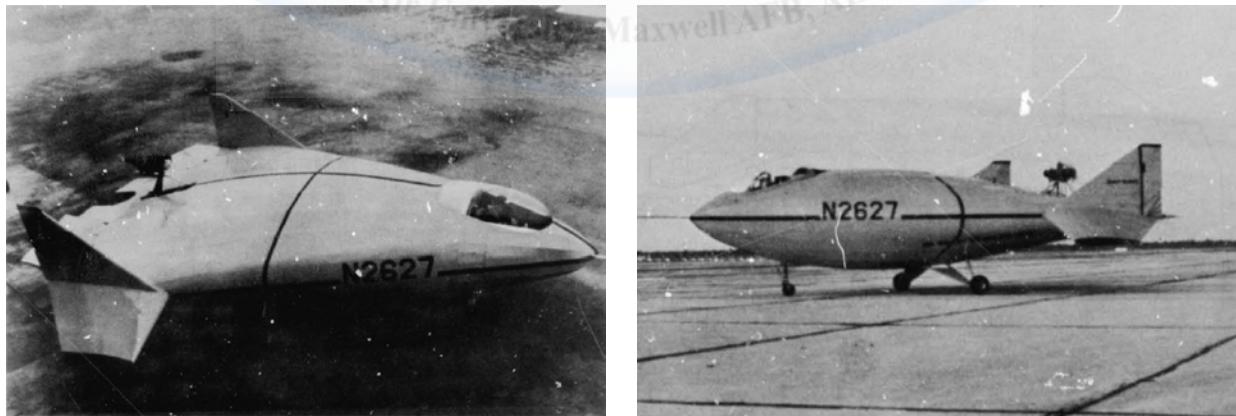


Figure 2: Two Photographs of the *Aereon 26*⁷

In the late 1990s, Lockheed Martin received NASA funding for a 'partially buoyant hybrid' aircraft to serve as an outsized freighter.⁸ Lockheed contracted with Advanced Technologies Group (ATG), a now defunct British company with several years of LTA aircraft construction experience, to serve as consultants in their efforts. The project was later abandoned

due to the contractors' inability to meet NASA's schedule.⁹ ATG went on to design and build the *SkyKitten*, a radio-controlled, unmanned, HA technology demonstrator. The *SkyKitten* was so named, because it was a small scale demonstrator for *SkyCat* technology. In 2000, a *SkyKitten* flight was observed by Lieutenant General Mike Duffy, USA, J4 on the Joint Staff.¹⁰ Shortly thereafter, the US Army and the Joint Staff sponsored the *SkyCat 1000 Engineering Study* to investigate HA in support of strategic lift.¹¹ It presented a detailed analysis of the construction, capabilities, and costs associated with a non-rigid HA with a cargo capacity of 1100 tons. The results of the study were generally well received within the Department of Defense (DOD), due to the revolutionary capabilities that were described and amply supported with engineering details.¹²

In 2002, the Joint Staff funded a Naval Air Systems Command (NAVAIR) study investigating the feasibility of HA.¹³ The results were promising enough that in 2004 the Under Secretary of Defense for Acquisition, Technology, and Logistics recruited the Defense Advanced Research Projects Agency (DARPA) to oversee prototype hybrid development with NAVAIR assistance.^{14,15} The program, dubbed WALRUS, was initiated as "an Advance Technology Demonstration program to prove the operational concept of a large lifting air vehicle capable of transporting a Unit of Action from "Fort-to-Fight" as a complete integrated package of personnel, equipment, and supplies."¹⁶ Commenced in FY2005, WALRUS received a large amount of press publicity and was referenced in several DOD and government documents at the time, but was not funded in the FY06 budget.^{17,18,19}

DARPA WALRUS aimed to develop a new approach to HA technology. Conventional hybrids are based on lift generated from lighter than air gas, aerodynamic lift and vectored propulsor thrust-lift. WALRUS sought to generate lift from other sources as well (gas

compression/expansion, gas superheating, etc.), to be independent of offboard ballast, and to base its operational utility on metrics comparable to current transport aviation. Two companies were awarded contracts, Lockheed Martin and Worldwide Aeros Corporation, to demonstrate approaches based on non-rigid and rigid hull designs. After funding was cut, in an effort to make best use of FY05 funding resources, DARPA reformed the WALRUS program to be a technology demonstration effort of those technologies that contributed to an advanced hybrid approach. This effort was executed through September 2006 and included several technology bench demonstrations, setting the foundation for two follow-on DARPA programs.²⁰

Independently of WALRUS, Lockheed Martin designed and built the *P-791* (See Figure 3).²¹ The *P-791* is a manned technology demonstrator hybrid flown by the company in 2006.



Figure 3: Lockheed Martin's *P-791*
(Source: Lockheed Martin at <http://www.lockheedmartin.com/products/p-791/>)

At the time, it was the largest HA successfully flown at approximately 120' long.^{22,23} Worldwide Aeros has not built a functioning hybrid, but it has, in two discrete programs, built and demonstrated its gas compression buoyancy control system and rigid structure construction. It has also conducted extensive design work on its rigid hull HA, the *Aeroscraft*.

Following cancellation of WALRUS, NAVAIR re-initiated discussions concerning the possible benefits of HA with the Joint Staff and the Combatant Commanders (COCOMs).²⁴ In 2008, NAVAIR was directed to initiate a Joint Capability Technology Demonstration (JCTD) for a hybrid ISR platform; the JCTD eventually became the Long Endurance Multi-Intelligence Vehicle (LEMV).²⁵ As an ISR asset, the LEMV is optimized for relatively high altitude (20K feet) performance, however, it also claims potential as a transport. US European Command (USEUCOM) took an interest and in 2009 initiated its *Point of Need Delivery Experimentation Campaign (POND)* study, the results of which are discussed in Chapter Four.



Figure 4: Northrop Grumman's LEMV

(Source: Northrop Grumman at <http://www.as.northropgrumman.com/products/lemv/index.html>)

In June 2010, Northrop Grumman was awarded a contract by the US Army for three LEMVs.²⁶ The LEMV program will produce the largest and most capable HA in the world. Northrop is subcontracting the construction of its lifting envelope to Hybrid Air Vehicles, Limited, a British company that is a direct descendent in terms of technology, personnel, and experience of ATG, the company that assisted Lockheed Martin in its Aerocraft program.

In March 2011, Lockheed Martin signed a contract with a private Canadian company to develop a family of commercial cargo airships.²⁷ This latest development is significant, because

it demonstrates civilian commercial interest with a willingness to fund HA development. The *Skytug* will be based upon the *P-791* and will build upon Lockheed's prior research.²⁸ This development is important for a second reason: It is the first step in overcoming the "chicken-and-egg" problem hampering the widespread use of HA. Several companies have conducted the engineering and analytic groundwork necessary to conclude that this class of aircraft is viable and advantageous in many ways to other aircraft but have lacked the necessary funds to construct an at-scale, operational prototype. Several potential customers of these companies have stated an interest in the aircraft—once constructed and demonstrated. But *until now*, no customer has been willing to fund the engineering to appropriately scale the concept.²⁹ This should open the door for further use of HA going into the future.

Summary

This chapter has provided the reader with a history of HA development to date. The following chapter will discuss several "basics" related to the operation and construction of airships, including HA, that are important to understanding their advantages and disadvantages and the technologies necessary to maximize the former and minimize the latter.

II: Airship Basics

In many ways, airship operation is closer to that of submarines than traditional heavier-than-air aircraft. In order to understand the implications of HA design and facilitate later discussions of technology development, several concepts should be explained. This chapter will provide that basis for the remainder of the paper.

Aerostatic versus Aerodynamic Lift

Blimps, dirigibles, and balloons all generate aerostatic lift, which is lift due to the buoyancy of the lifting gas. The air vehicle's envelope serves as a displacement hull full of lifting gas that is less dense than the air it is displacing. When the weight of the hull (structure plus contained gas) is lighter than the air it displaces, the hull is "buoyant" and floats. In this case, buoyancy equals lift. Hydrogen and helium are common lifting gases due to their low

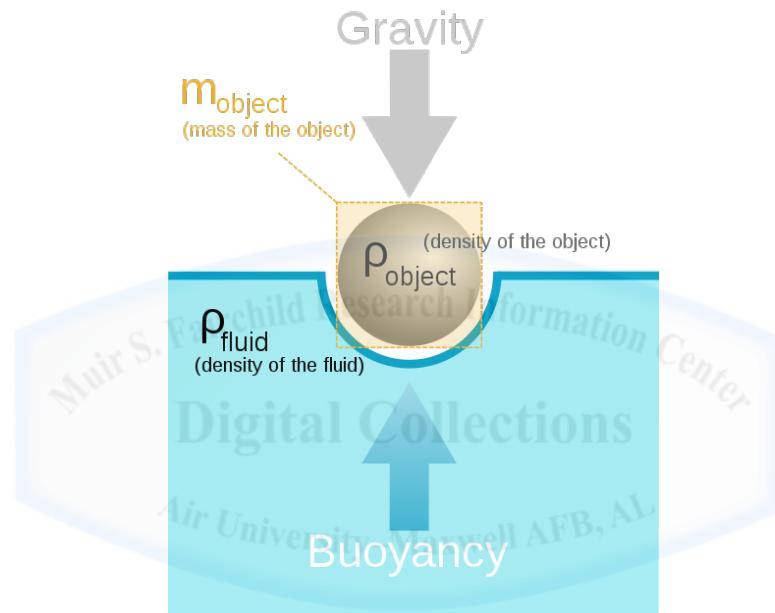


Figure 5: Buoyancy
(Source: Wikipedia.org at <http://en.wikipedia.org/wiki/Buoyancy>)

density at atmospheric pressure and room temperature, although hydrogen presents flammability dangers and is not typically considered in modern uses. Hydrogen provides close to 70 pounds of lift per 1000 cubic feet while helium provides 65 pounds of lift.

Traditional aircraft generate aerodynamic lift, a force that is perpendicular to the motion of air over an airfoil—the wing. (See Figure 6) A significant difference between the two is that aerodynamic lift requires motion of the airfoil, in other words, horsepower and fuel.³⁰ This brief discussion already points to a major advantage of LTA aircraft over traditional aircraft: The engines only need to move the airship, not lift it.

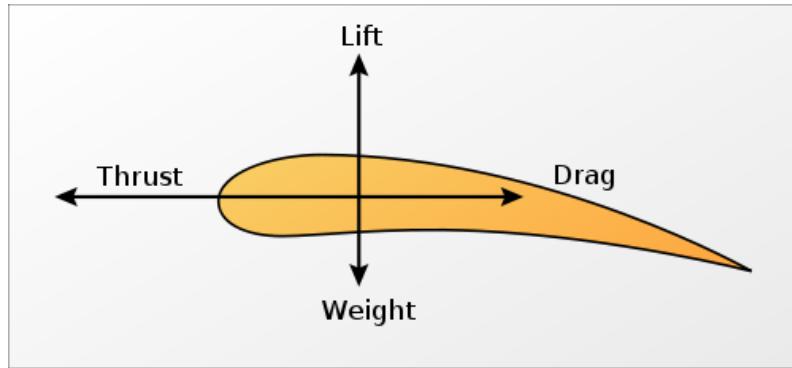


Figure 6: Aerodynamic Lift
 (Source: Wikipedia.org at [http://en.wikipedia.org/wiki/Lift_\(force\)](http://en.wikipedia.org/wiki/Lift_(force)))

HA are not LTA and typically generate 80% of their lift through buoyancy. They rely upon the shape of their hulls and the airflow over that hull to generate aerodynamic lift, contributing the final 20%. By developing lift through each of these two discrete mechanisms, HA are able to take advantage of the “free” lift provided by buoyancy while also taking advantage of the handling and maneuverability of traditional aircraft.

Rigid Versus Non-rigid

Digital Collections

Airships fall into three classes—rigid, non-rigid, and semi-rigid (the present-day Zeppelin NT is an example of a semi-rigid). In a non-rigid airship, the lifting gas is pressurized within a fabric envelope, typically to 0.07-0.1 pounds per square inch, giving the envelope its shape and rigidity. Rigid airships, dirigibles, are constructed with a solid hull structure, typically of aluminum, containing individual gas bladders providing lift to the structure. The drawback to a rigid airship is that the weight of the structure itself detracts from its performance, either in terms of cargo capacity, endurance, or maximum altitude. The comparable drawback to a non-rigid airship is that the size of the envelope is limited by the strength of the envelope fabric; the larger the airship gets, the greater the stress in the fabric. There are other perceived disadvantages to the non-rigid airship, but these will be discussed in the following chapter.

Pressure Height

As an airship gains altitude, its lifting gas expands as atmospheric pressure decreases.

This is necessary, for in order to continue providing buoyant lift, the lifting gas must displace the same *weight* of air, and because air density decreases with altitude, a given weight of air fills more volume. Expansion of the lifting gas, however, increases the pressure within the constant volume of the envelope, stressing it. To allow for this expansion without risking the structural integrity of the envelope, airship designers make use of smaller, internal envelopes called balloonets that are filled with ambient air. The balloonets are allowed to expand and contract opposite the lifting gas by venting to or filling from the atmosphere. (See Figure 7) On the ground, the balloonets are filled with ambient air while the rest of the envelope is filled with

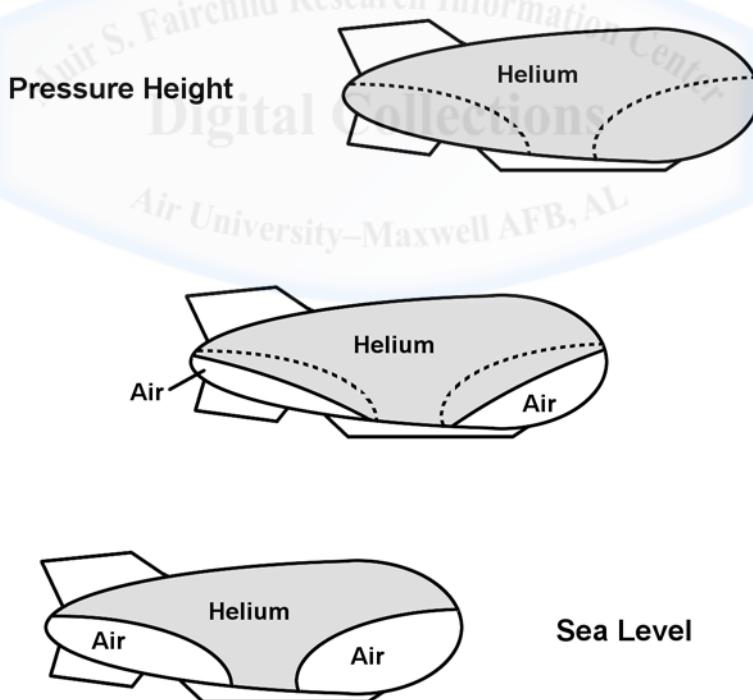


Figure 7: Ballonets at Altitudes up to Pressure Height

the lifting gas. As the airship gains altitude, the lifting gas expands; the balloonets are vented to atmosphere, and the expanding lifting gas pushes air from the balloonets. The altitude at which

the lifting gas has expanded to completely fill the main envelope and completely empty the balloonets is called the *pressure height*. This determines the maximum altitude for that airship. Conversely, as the airship descends, the lifting gas contracts and atmospheric air is pumped into the balloonets to maintain relative pressure and total volume of the main envelope.

The pressure height for a given airship is variable and presents the operator with a trade-off between altitude and cargo capacity: If a greater volume of air is set in the balloonets at takeoff, there is more room for the lifting gas to expand as the airship ascends, which equates to a higher maximum altitude. This comes at a cost, however, because a higher balloonet volume equals a lower volume of lifting gas at takeoff (within the constant volume main envelope), which means less lift and therefore less maximum cargo. This balance between these two planning factors, maximum altitude and maximum cargo capacity, can be adjusted at the commencement of each mission, however, it can be very difficult, or expensive, to make this adjustment mid-mission. This will be further discussed in the following chapter.

Although not related to the pressure height, the existence of balloonets within the main envelope allows the operator to control the trim of the airship as well as its maximum altitude. (See Figure 8) Because the ambient air in the balloonets is heavier than the lifting gas in the main envelope, it is effective as ballast. Rather than venting from or pumping to all of the balloonets equally, for instance, the operator could choose to vent more air from the aft balloonets making the aft end of the airship lighter than the forward end and causing the airship to pitch upward. The same principle of ballasting using balloonet air can also apply to roll angle to the left or right with implications for cargo loading.

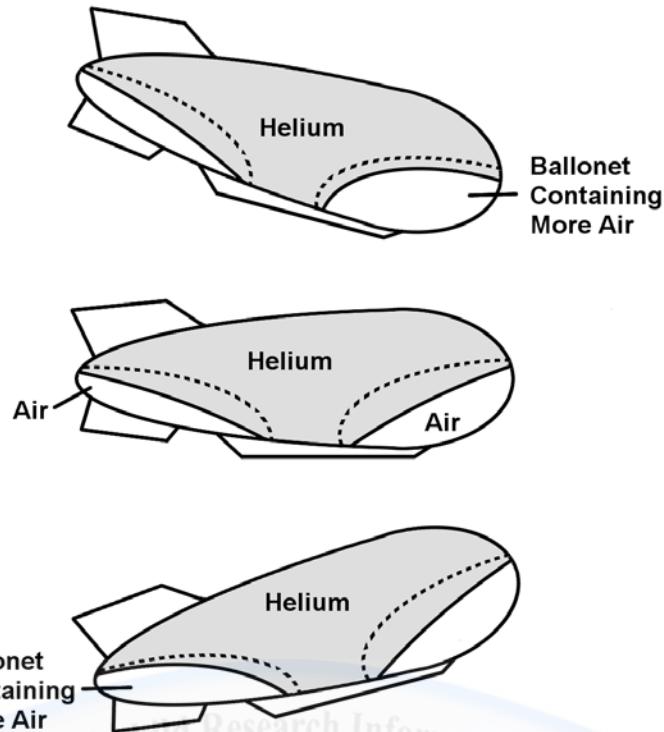


Figure 8: Ballonets to Adjust Airship Trim

Buoyancy Compensation

Buoyancy compensation is a limiting factor in airship operation and has driven some of the interest in HA. An airship that takes off with neutral buoyancy does so when the aerostatic lift produced by the lifting gas equals the combined weight of the vehicle, including the structure, payload, and fuel. As an airship transits, it depletes fuel, the weight of the airship decreases, and it gains significant positive buoyancy. This is problematic from a control perspective. Historically, there were two solutions to this problem. The first was to vent hydrogen to the atmosphere to eliminate the excess buoyancy, which was an acceptable method when hydrogen was the primary lifting gas. This is no longer the case, however, as today helium is the primary lifting gas and is much more expensive than hydrogen. The second solution was to gather the engine exhaust and condense and recover the water it contained, which was then stored onboard as ballast to compensate for the fuel depleted.

For an airship transporting cargo, there is a second issue concerning buoyancy. An airship arriving at its destination approximately neutrally buoyant will then unload its cargo—for the purposes of this paper, up to several hundred tons worth. Each ton of cargo removed, becomes a ton of excess lift that the vehicle then possesses. This can be overcome by loading ballast, either in the form of cargo to be transported in the other direction or water. In the case of military transport landing in an austere location, however, it is quite reasonable to assume that there is no outbound cargo to be picked up or available water to serve as ballast.

Buoyancy compensation therefore merely refers to those methods employed by the HA designer to overcome these problems. The dual nature of the lift utilized by HA can overcome some if not all of this problem, which will be discussed in the next chapter, but at large cargo capacities, this does present a technology and design challenge that must be overcome.

Summary

This chapter has presented the basic principles necessary to understand HA for military use: rigid versus non-rigid construction, pressure height, and buoyancy compensation. The following chapter will further describe HA construction and operations in order to highlight their advantages and present a case for their adoption.

III: Hybrid Air Vehicles

Hybrid air vehicles are sufficiently different from all other forms of aircraft that a description of their construction is helpful. Following a general description, this chapter will discuss the operational characteristics crucial to understanding HA utility to the warfighter. The chapter will conclude with the author's appraisal of the utility of this new class of vehicle.

It should be noted that the following description focuses on non-rigid HA, of which the *SkyKitten*, *SkyCat1000*, *P-791*, and *LEMV* are. They share many characteristics and will form the basis for the following discussion. This is not to discount the *Aeroscraft*, a rigid HA, however, the former have been built and flown, or at least extensively modeled, while the latter has not. The *Aeroscraft* also possesses subsystem and integration challenges that push the boundaries of today's technology, and a greater amount of engineering and development would have to be carried out prior to a functioning prototype being flown. Ultimately, this is not to say that the *Aeroscraft* is not a viable concept, but that the author has concluded that if it chooses to pursue HA, DOD would be best served *at this time* by focusing its funding on non-rigid aircraft.

Construction

Non-rigid HA are all of similar design, the largest component of which is the lifting envelope, which is constructed out of a material, or materials, that serve three distinct functions: provide structural strength, prevent leakage of the lifting gas, and prevent weathering. Fabrics therefore need to be strong and tear-resistant, impermeable, and able to resist environmental effects. At the same time, the materials chosen need to be flexible and easily machined to aide in manufacturing. No single material possesses the properties to adequately accomplish these three functions, however, a composite envelope constructed of two or more is possible. A composite fabric employing Tedlar® (for its excellent weatherability) and Mylar® (for its low permeability) coatings surrounding a woven material of Vectran® fibres meets the needs of a LTA aircraft.³¹ In each case the envelope is constructed of three separate lobes arranged side-by-side, making the aircraft wider than it is tall. Figure 9 below includes images from the *SkyCat 1000* study but provides a general illustration of these components in all non-rigid HA.^{32,33}

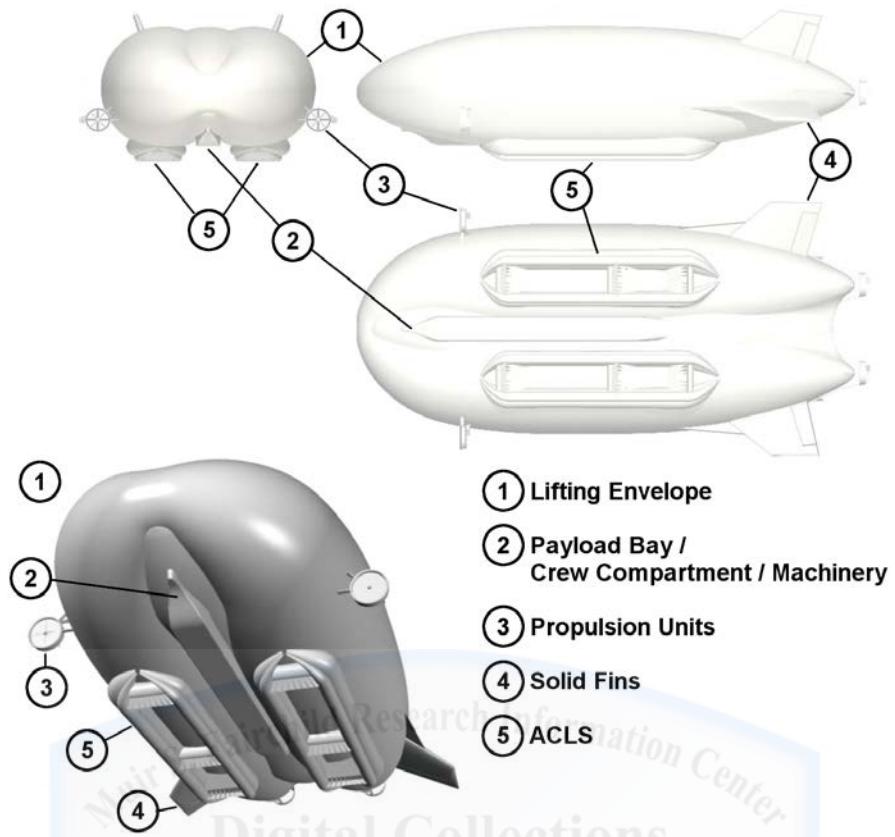


Figure 9: Structural Components of Non-rigid Hybrid Aircraft

Slung beneath the central lobe is the largest solid structure, typically consisting of the payload bay and/or cargo bay, crew compartment, and machinery associated with the fuel and ballast systems. Mounted to the lifting envelope are several propulsion units, consisting of shrouded propellers attached to assemblies that allow movement in multiple axes. Also mounted to the lifting envelope are several solid fins. For HA to be effective as heavy lift vehicles, the payload bay would be constructed with ramps to allow Roll-on/Roll-off of its cargo, including wheeled vehicles, tanks, etc. This aspect of its construction speeds loading and unloading and contributes to its operational advantages. The cargo portion of the *SkyCat 1000* is 265 feet long by 44 feet wide by 27 feet high internally³⁴, divided into three decks, and supports Roll-on/Roll-off cargo loading; the *Blue Horizons Airlifter* would be larger.

All of the HA currently in development, including the *Aeroscraft*, make use of what is known as an Air Cushion Landing System (ACLS). In each variation, the ACLS is constructed of an inflatable skirt, similar to a hovercraft. When the HA is on the ground taxiing, positive airflow into the skirt reduces friction across the ground and allows the vehicle to ‘glide.’ When the HA is parked, airflow out of the skirt creates a suction that holds the vehicle to the ground. When in flight, the skirt is deflated and retracted into the aircraft’s body to reduce drag.

Debarkation in Austere Landing Sites

Use of an ACLS as opposed to traditional landing gear allows the HA to land on any relatively smooth surface, including unfinished ground, ice, or even water. Obstacles up to 3-4 or more feet high would not pose a problem to the operation of the vehicle. It is this ability to not require an air- or seaport of debarkation (APOD/SPOD) that is one of the strongest advantages of HA to the military. Related to this is the fact that APODs/SPODs are vulnerable to enemy attack. Runways can be bombed or blocked; ports can be mined or blocked; a coastline can be heavily defended against amphibious assault; the Ground Lines of Communication (GLOCs) from the port to the operating area (OA) can be subjected to Improvised Explosive Devices (IED), ambushes, and the like. Each of these can be circumvented by a HA with the ability to fly over them.

Survivability

There are hazards that the HA will not be able to fly over—or not be able to outrun. Despite its large size, however, the survivability of HA is much higher than most assume. The *SkyCat 1000* study conducted detailed analyses of man-made and natural threats. Inclement weather, in the form of high winds, snowfall, and lightning strikes, do pose dangers to a massive HA, however, weather prediction and proper route planning can mitigate these concerns to a

large degree. In no case did these dangers lead to the catastrophic destruction of the vehicle, but instead to mission degradation, in terms of transport time or reduced cargo capacity, or to the need to conduct repairs.

By far the greater threats are man-made. The *SkyCat 1000* study investigated the following dangers, judged to be common throughout the world: 7.62mm, 12.7mm, 14.5mm armor piercing incendiary rounds (API), 23mm API and high explosive incendiary tracer (HEIT) rounds, and Man Portable Air Defense Systems (MANPADS) including the Stinger missile, SA-7, -14, and -16.³⁵ They noted that the most vulnerable areas of the HA were the propulsion, cargo compartment, lifting envelope, and crew stations. The most pertinent to this discussion is the lifting envelope, which will be discussed here. Their analysis determined that up to several hundred rounds of small caliber gunfire would have minimal effect on the operation of the aircraft. A MANPADS strike would have a much greater effect, but even that would not result in an instantaneous kill, such as would occur with a normal aircraft. Even after suffering these attacks, the HA would have several *hours* of flight time before it is forced to land—a controlled landing that could be conducted in a safe manner, *not* a crash landing.

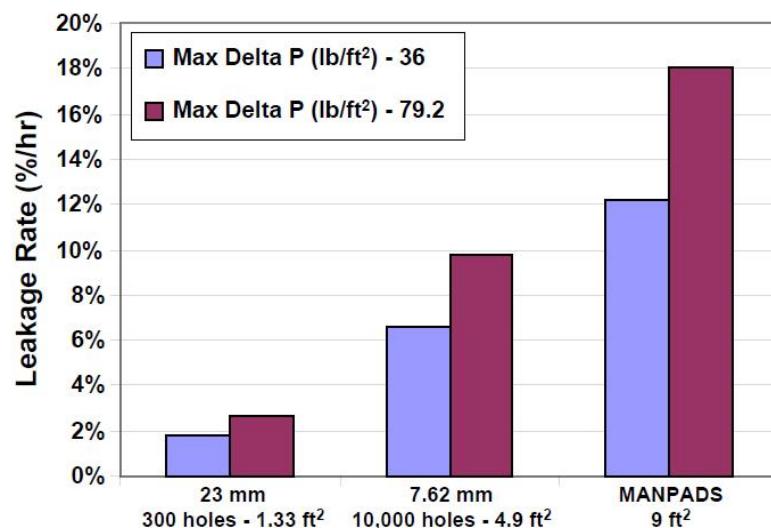


Figure 10: Helium Leakage Rates for Differing Damage Levels

Figure 10, taken from the *SkyCat 1000* study, lists the leakage rates of helium from the lifting envelop for various attacks.³⁶ The square footage (x-axis) refers to the size of the hole generated for each type of attack. The magnitude of this leak rate is due to the fact that the envelope is only slightly pressurized compared to the atmosphere, providing only minimal motive force to eject the helium. Additionally, in the case of damage from the smaller projectiles, companies are investigating and perfecting technologies that would allow the envelopes to self-heal, eliminating entirely the danger posed by the most common manmade dangers. The survivability of HA is demonstrated anecdotally in this account offered by Major Charles Vogt, USAF:

After a nearly 4,000 mile trip, a Canadian research balloon carrying an atmospheric research payload came to rest in a field in Finland. The 100 meter tall balloon had failed to terminate its three-day mission and drifted for 10 days over the Atlantic in August 1998. During that trip the rogue balloon threatened trans-Atlantic flight routes and caused numerous flights to be redirected to prevent a collision with the erratic flight. The balloon, which can reach altitudes as high as 130,000 feet, caused enough concern to generate military responses from the United States, Canada, and Great Britain. Early in the episode the Canadian Air Force scrambled F-18 fighters to try to destroy the vehicle. Despite over 1,000 twenty millimeter cannon shots at the balloon, the fighters were unable to bring the vehicle down. The exact altitude of this engagement was not verified. However, the damaged balloon continued to cross the Atlantic Ocean at altitudes between 27,000 and 37,000 feet. Many observers thought this errant flight might be the first lighter-than-air vehicle to make a round-the-world circuit. But not to be, on 3 September 1998, the balloon's flight ended.³⁷

Direct “Fort to Fight” Transport

HA would provide the DOD with a transport able to load several hundred tons of personnel, arms, and equipment, fly them directly to an austere landing site and offload them in a timely manner. This capability offers several advantages over today. Currently, moving troops and their equipment from home base to the OA involves numerous steps across various

intermodal transportation networks, the transition between each of which adds time, complexity, and cost to the movement.

A hypothetical Army unit based INCONUS and deploying overseas needs to do the following: Transport all personnel and equipment, including vehicles, arms, ammunition, and other supplies, from their home base to an appropriate air- or seaport. Load the above on ships or aircraft as appropriate. Transit to the APOD/SPOD within a friendly nation able to receive the transport vehicles and closest to eventual operations. (Because personnel typically do not travel with their gear, a certain period of time is required to marry troops to their equipment.) Transport via other means from the port to the eventual OA. Establish operations.

The logistic complexity of the movement of troops from the receiving APOD/SPOD to their OA is vitally important, so much so that it is given its own term: Reception, Staging, Onward-movement & Integration (RSOI). A significant advantage offered by HA is that RSOI would be greatly simplified; utilizing HA, that same Army unit described above would need only to do the following: Transport all personnel and equipment, including vehicles, arms, ammunition, and other supplies, from their home base to an appropriate airport. Load the above onto the *same* aircraft. Transit to the eventual OA; during transit, conduct training, planning, and even preventative maintenance on arms and equipment. Establish operations. The delays and inefficiencies inherent in conducting transitions between several intermodal transportation networks are eliminated.

Lift Capacity and Operational Flexibility

As discussed in Chapter Two, HA develop lift through aerostatic lift (buoyancy) and aerodynamic lift, generated by the airfoil contour hull in forward flight. In addition, every modern hybrid concept uses thrust vectoring to provide additional lift at takeoff. This

combination of lifting mechanisms generates the massive lift capacity associated with these aircraft, which is necessary to carry the empty weight of the vehicle (including the weight of the lifting gas and air in the ballonets), the weight of the fuel, and the weight of the cargo. It also allows the operator a great deal of flexibility in planning airlift operations.

The nominal capabilities of the *Blue Horizons Airlifter* in terms of payload, range, and altitude are detailed in Chapter Five, however, these capabilities are actually one set of characteristics in a wide trade space. As stated in Chapter Two, less cargo could be carried in exchange for a higher operating altitude. If the transit merely crossed an ocean, the altitude could be reduced for greater cargo capacity. Range is ultimately determined by fuel loading, therefore carrying extra fuel in place of cargo could increase the range of the vehicle; the reverse is also true. This flexibility is unmatched by other mobility assets.

Vertical Lift and/or Short Runway Requirements

HA rely upon aerodynamic lift to achieve their maximum cargo capacity and therefore require a long runway at take-off to reach suitable air speed. This is not particularly problematic as take-off with maximum cargo will typically occur in CONUS at the start of a deployment. At the end of a transit, after having burned a significant portion of fuel, HA will closely approach neutral buoyancy and will not depend as much on aerodynamic lift. Short Take-Off and Landing, or even Vertical Take-Off and Landing (VTOL), is possible. The HA could be operated as a VTOL vehicle at *all* times, assuming its total weight is less than its aerostatic lift, which would be a case where the aircraft is purposely *not* loaded to its maximum capacity.

Fuel Costs

The ever-rising cost of fuel will continue to burden the DOD in the coming decades. The use of HA offer significant cost savings due to their fuel efficiency relative to conventional

aircraft. The *SkyCat 1000* study compared the SkyCat 1000 with two cargo aircraft: the Boeing 747-400F, which was the freighter with the largest production in the world, and the McDonnell Douglas MD-11F, then considered the most economic commercial freighter. Two analyses were conducted: moving equal cargo tonnage or flying an equal number of sorties. The results are presented in Figures 11 and 12. The average cost per ton mile of the SkyCat 1000 was three times less than the Boeing 747 and almost 2.5 times less than the MD-11F.

Commercial Comparison Tonnage Fort Lewis to Kimhae AB							
Aircraft	Total Payload Capacity in Tons	Payload Moved in Tons @ 80% Load Factor	Sorties Required	Total Cost per Sortie	Total Cost for Sorties Required	ATM @ \$.57 per Gallon Fuel Cost (FedEx)	ATM @ \$.90 per Gallon Fuel Cost (Government)
MD-11F	101	889	11	\$84,688	\$931,565	\$0.23	\$0.25
747-400F	102	897	11	\$111,456	\$1,226,016	\$0.30	\$0.33
SC 1000	1100	880	1	\$360,835	\$360,835	\$0.09	\$0.10

Figure 11: Tonnage Comparison

Commercial Comparison Based Equal Number of Sorties				
Aircraft	Number of Sorties	Payload Moved in Tons	Total Cost	Cost per ATM (Available Ton Mile)
MD-11	124	10,019	\$10,466,817	\$0.23
747-400F	124	10,118	\$13,820,544	\$0.30
SC 1000	124	108,907	\$45,896,741	\$0.09

Figure 12: Commercial Comparison based upon Number of Sorties

Separately, the *POND* study offers the following:

Additionally, airship technology significantly reduces the costs of deployment. As the fully burdened cost of fuel becomes a key consideration in future platforms, the fuel efficiency of airship technology becomes a key consideration. A study by the RAND Corporation of hybrid technology concluded that a hybrid airship would use approximately 80 percent less fuel than C-17 platforms performing the same mission. The Air Force Global Mobility (GLOMO) Exercise 10 determined that the combination of hybrid airships with C-17's and surface vessels would have resulted in fuel savings in the billions of dollars for a single 30 day deployment period. Applying these principles to Operation ENDURING FREEDOM, the use of airship technology to support the rotation of assets results in a 50 percent reduction in deployment time and a 30 percent reduction in fuel costs. One research paper proclaims: "*Economic indicators reveal 60% reduction in cost over fixed-wing aircraft in total cost per ton-mile.*" In a more recent RAND Study, the Cost Per Ton Mile of a hybrid airship was \$0 .22, while a C-17 performing the same mission was \$1.2017. This represents

approximately a 80% reduction in costs per ton mile using hybrid technology for the scenarios that were tested against.³⁸

The need to move military supplies in a cost effective manner will only grow in importance for the United States. Hybrid aircraft provide possibly the most fuel efficient means of strategic mobility, and these cost analyses do not take into account the possibility of further advances in efficiency and power generation. Due to the ability to eliminate several “layers” of intermodal transportation between a unit’s home base and its eventual OA, the cost benefits provided by HA are actually greater than an analysis focusing solely on fuel savings.

DOTMLPF Issues

While this research effort did not concentrate on the full DOTMLPF issues involved in the future employment of HA by the military, these are significant issues that must be considered. *POND* examined these issues, a summary of which is found in Appendix A.

Summary

Hybrid aircraft offer many compelling advantages to the warfighter and to the DOD. The ability to provide direct “fort to fight” transport and debark combat-ready forces in austere locations will maximize their chances for success on the battlefield. The fuel savings and their ability to reduce the logistic burdens of deployment provide a strong business case for their procurement. But is embarking on a new acquisition program responsible in today’s fiscal environment? A review of the warfighter’s needs and projected needs is perhaps the best way to make this determination, and that will be conducted in the following chapter.

IV: Utility of a Heavy Lift / High Speed Hybrid Aircraft

In contemplating the purchase of any new capability, the first order of business must be to determine if such a capability is necessary, for if it is not, time and money spent are wasted

and, even worse, detract from the development of capabilities that are necessary. In an era of fiscal constraint, this analysis must be conducted thoroughly and without prejudice. The DOD must concentrate its efforts on those acquisition programs that will best support the warfighter, most contribute to mission accomplishment, and do both in a manner that is affordable and responsible. To make this determination, one should listen to today's customers, the Combatant Commanders (COCOMs), as well as attempt to forecast the military's needs in studies that examine plausible future scenarios. Additionally, the Science and Technology (S&T) community must advise on technology maturity, and there must be a dialogue to weigh Tactics, Techniques, and Procedures (TTP) with capability strengths and weaknesses in order to establish the right and acceptable operational air vehicle.³⁹

Historical Airlift Assessments

The 1992 National Security Strategy states, “We must be able to deploy substantial forces and sustain them in parts of the world where pre-positioning of equipment may not always be feasible, where adequate bases may not be available, and where there is less-developed industrial base and infrastructure to support our forces once they have arrived.”⁴⁰ Those words are more relevant today than when first written. Since that time, several research efforts have proclaimed the existence of an “airlift gap,” the inability of the services to jointly deliver the men, arms, and supplies to a notional fight in a timely manner. Discussing air mobility in 2001, Burns wrote, “According to our national civilian and military leadership, our national security interests depend on our ability to project power rapidly. With the loss of strategic forward bases for U.S. forces, the ability to deploy those forces has become more important than ever. The capability of the current airlift force has become a limiting factor for the range of credible responses the U.S. can launch to crises.”⁴¹ Comparing our nation’s power projection aspirations with its capabilities,

Clifton in 2002 wrote, “There is a serious disconnect between the ideas and reality.”⁴² In 2003, Eisenhut wrote, “Currently our ends, ways, and means are not in balance. Mobility Requirements Study-05 and the GAO audit of this study both show a shortfall of airlift. The major risk involved in this shortfall is lack of flexibility.”⁴³ He goes on to state, “The only way to reduce the strain on our airlift system is to reduce our worldwide commitment. This is not likely to happen.”⁴⁴

Recent developments have seemingly eliminated this gap—at least in terms of strategic airlift. In a November 2009 report regarding defense acquisitions, the Government Accountability Office (GAO) determined that

DOD appears to have addressed its strategic airlift gap, but there is a potential future tactical airlift gap for moving medium weight equipment. Also, questions regarding how the Air Force will meet the Army’s direct support mission have not been resolved. DOD is [procuring] 23 additional C-17s, which DOD officials believe more than offsets the strategic airlift gap associated with the restructured C-5 modernization program. However, there is a potential gap in the tactical airlift of medium weight loads beyond the capability of the C-130s. The C-17 is the only aircraft capable of moving this type of Army equipment within a theater of operation, *although not to austere, short, or unimproved landing areas* (italics added).⁴⁵

The ability of the current fleet to not land in “austere, short, or unimproved landing areas” is a major reason for advocating the development of HA. Additionally, the “questions” raised in the paragraph above are serious and warrant appropriate consideration.

Are 213 C-17s enough to perform both strategic and tactical missions? What are the potential impacts on C-17 service life, maintenance, and availability from its expected increased use in the future for the tactical airlift of heavier and bulkier Army equipment? How will the Air Force meet the Army’s time-sensitive mission-critical requirements with 40 fewer C-27J aircraft?⁴⁶

The answers to these questions are currently unknowable, but the introduction of HA to perform some combination of strategic and tactical airlift would ease the burden on the C-17 fleet and render these issues moot.

Criteria for Assessment	Description
Cost	<ul style="list-style-type: none"> The cost of purchasing and operating mobility forces over the next several decades.
Cargo Deliveries to Major Regional Conflicts	<ul style="list-style-type: none"> The most demanding scenario for mobility is likely to remain two major regional conflicts that occur at nearly the same time.
Deliveries During the Halting Phase	<ul style="list-style-type: none"> The first U.S. forces would need to arrive within two to three weeks to halt an enemy assault. The amount of outsize cargo that different mixes of mobility forces could deliver to regional conflicts.
Flexibility to Handle Changes in Deployment Schedules	<ul style="list-style-type: none"> Commanders would probably prefer DOD to purchase a set of mobility forces that would give them flexibility to change their deployment plans to suit changing conditions.
Vulnerability to Enemy Attack	<ul style="list-style-type: none"> An enemy would have a strong incentive to slow U.S. deployments by targeting ports and airfields. Access to critical sea lines, choke points, en route airfields, and the air space of other countries.
Flexibility for Delivering Cargo to Smaller Operations	<ul style="list-style-type: none"> Lesser regional contingencies may pose different sorts of problems for strategic lift: Some areas lack long runways, deep ports, and equipment to unload planes and ships. Peacekeeping Missions, Humanitarian Assistance, and Evacuations of Noncombatants Peace Enforcement Missions
Other Special Airlift Missions	<ul style="list-style-type: none"> Long-Range Airdrops of Large Forces Intra-theater Deliveries Direct Deliveries

Figure 13: CBO Criteria to Assess Mobility Needs

A Congressional Budget Office (CBO) study conducted in 1997 entitled “Moving US Forces: Options for Strategic Mobility” actually discounted not the existence of an “airlift gap” but the ability to accurately assess such a gap. “Because of the uncertainties in forecasting mobility requirements, it is hard for policymakers to know how much lift the United States needs for the future … Ultimately, that judgment is probably a subjective one, based on what decisionmakers believe is a reasonable balance between cost and capabilities.”⁴⁷ The study then

offered a series of criteria to assist policy makers in analyzing mobility requirements. Figure 13 above lists the criteria, including a short description.⁴⁸ The capabilities of HA seem to support the needs outlined in this criteria.

As the concept of hybrid airships gained widespread attention following the conduct of the *SkyCat 1000* study and DARPA's WALRUS program, several studies over the past decade have specifically mentioned HA as alternatives to assets in the current inventory. Major Charles Newbegin, a student at the US Army's School of Advanced Military Studies in 2003, wrote

The SkyCat airship is an aircraft that could provide the transport capability to rapidly deploy heavy forces into an area of operation without relying on APOD/SPOD facilities. ... The DOD, by sponsoring airship studies, has already demonstrated it is interested in what these aircraft can do. ... The DOD should allocate funding for the construction of a SkyCat 500 or 1000 prototype for the purpose of finding out if these airships can actually perform as modeling indicates.⁴⁹

Although very large airlift capability is recognized as being potentially transformational, there has been a lingering concern about technical feasibility and a lack of appetite to embark on an entirely new path with all of the uncertainty that this involves: technical, programmatic, and cost. Additionally, airships have a clear whiff of extinction about them, being a technological approach that was left behind ostensibly in the 1930s and finally disappearing in the early 1960s. These uncertainties are, perhaps, at the bottom of the stop-start approach to HA programs over this past twenty years. While the COCOMs must continue to explore requirements and capabilities studies to make a case, there is a need for the S&T community to validate the potential for this technology, affordably, in order to buttress the feasibility case.

The Need Today

In 2009, USEUCOM undertook its *POND* study that

Focused on the capability gap of responding rapidly to a crisis anywhere in the COCOM's Area of Responsibility (AOR) due to a lack of lift capable of circumventing the infrastructure challenges existing in significant portions of the AOR. Specifically, the Experimentation campaign sought to identify existing and developing capabilities that could enable a COCOM to respond to a crisis within three to five days, anywhere in the COCOM's AOR, independent of receptive infrastructure or services available at the point of need. This requirement is driven by the vast distances and austere infrastructure that define the Caucasus, Balkan, and African regions.⁵⁰

US Africa Command (USAFRICOM) and USTRANSCOM also participated in and endorsed the results of the study, because “the requirement for a point of need delivery capability is widely recognized and articulated in a number of strategic documents and Joint Concepts.”⁵¹ These documents include:

Guidance for the Development of the Force: DoD components will “*develop high-payoff technologies that improve theater access through high-speed, austere access, inter/intra-theater airlift and sealift, and reduction of modal transfers to expedite movement of forces and sustainment to the user.*”

The National Military Strategy of the United States of America: “*The United States will conduct operations in widely diverse locations – from densely populated urban areas located in littoral regions to remote, inhospitable and austere locations.*”

Capstone Concept for Joint Operations: “*Joint Forces ... will require a mix of air and sea strategic and operational lift capable of delivering forces and materiel to their destinations, often in the absence of capable airfield and port facilities.*”

Focused Logistics Joint Functional Concept: “*...the future Joint Force-including its logistics components-will be rapidly deployable, employable, and sustainable throughout the global battlespace regardless of anti-access, or area-denial environments.*”

Joint Logistics Joint Integrating Concept: “*...the Joint Force requires the ability to deliver forces directly to the point of need, bypassing traditional strategic ports...*”

Seabasing Joint Integrating Concept: *Requires the ability to provide theater access at unimproved ports.*

Joint Logistics (Distribution) Joint Integrating Concept: *Rapidly deploy modular, scalable joint force warfighting capabilities with sufficient accompanying supplies...across strategic and operational distances via high-speed mobility and maneuver platforms, enabling entire combat ready units to arrive in theater within hours or days not weeks...*

Seabasing Joint Integrating Concept: Requires the ability to “operate at will” in an anti-access environment by providing the JFC with “multiple access options to complement forward basing in Joint Operations Area.”⁵²

Perhaps the greatest advantage offered by the use of HA is its ability to land and debark forces in austere environments thus eliminating the need for sea- or airports of debarkation. The findings of the *POND* study demonstrate this to be the case but report several other advantages as well.

POND’s efforts began with the development of a problem statement, to be used as the measuring stick against which the results of their analysis could be compared. That statement read: “*EUCOM/AFRICOM require a capability to deliver within 3-5 days a ready-to-employ, task-organized element up to brigade or equivalent, to or from a point of need, independent of receptive infrastructure.*”⁵³ Using DOD standard modeling applications, the study examined a baseline Defense Planning Scenario using existing lift capabilities. The study concluded that “deployment timelines are measured in months rather than days to get an operationally relevant force to a point of need. The workshop concluded that the current lift platforms: 1) cannot deliver a capability directly to a point of need, [and] 2) require the use of existing infrastructure, leading to delays in deployment timelines.”⁵⁴ The next phase of the study investigated possible technologies to mitigate these shortcomings. It is important to note that the participants were technology-agnostic, meaning that no prior bias existed in seeking solutions. “Industry representatives provided presentations of 25 potential technologies that were evaluated for their viability to resolve the problem statement. The participants determined that hybrid airship technology, as well as the fixed and rotary-wing Joint Future Theater Lift (JFTL) technologies, held the greatest potential to fill the COCOM’s capability gap.”⁵⁵ The study concluded, “The experiment determined that the only platform that had the capability to meet the requirements outlined in the problem statement was a hybrid airship capable of lifting at least 200 short tons.

Other platforms, sea and air, did not have the range, lift capabilities, or required host nation support to move a unit to the point of need.”⁵⁶

POND determined that a hybrid air vehicle with a cargo capacity of 200 tons would be able to meet the requirements of their problem statement; a 1300 ton vehicle, as recommended by this paper, would easily surpass the benefits as analyzed in that study. Full conclusions from the *POND* study can be found at Appendix B.

The Future Need

The year 2035 will no doubt bring with it many surprises to those of us serving in the armed forces. The status of the United States, the roles and missions of its military, and its relative strength in the world will differ from today, however, to maximize the chances of maintaining a preeminent position on the world stage requires thoughtful foresight and planning. It is imperative that today’s service members look ahead and begin planning today for the world of that time. To do so effectively requires imagination, thoughtfulness, logic, an adherence to realism, and the time to devote to efforts outside of the typical day-to-day operational urgency. It also requires a skillset not typically present in the standard service member or at least not pertinent to the vast majority of today’s military billets. Luckily, the US military recognizes the importance of forecasting for this far future and pulls personnel from the normal grind to do so.

One such effort was begun in December of 1994, when General Ronald Fogleman, Chief of Staff of the Air Force, tasked Air University to conduct a study to identify the concepts, capabilities, and technologies that the United States would require to remain the dominant power in the first quarter of the 21st Century. The study were titled *Air Force 2025 (AF2025)*, and key to that effort was an internal research paper called *Alternate Futures for 2025* that generated six futures scenarios. Five of these are set in 2025, while the sixth served as a check point set in

2015. In five of the scenarios, there exist common threads that point to the strong applicability of a HL/HS HA capability. (The only scenario that did not include these common threads described a militarily weak United States no longer serving in an influential role in the world.) One future described a strategy focused on rapid power projection and civil-military operations capabilities; projection is chosen because of the dangers in maintaining concentrated overseas forces, and because most states no longer accept a permanent US military presence. “Once a crisis action area has been identified, assets must be transferred rapidly to the scene. In the majority of responses, light mobile ground forces are used to resolve the situation.”⁵⁷ In another scenario, the military is specifically equipped to meet all known contingencies anywhere in the world. In yet another, a “carrot and stick” approach is recommended wherein our forces conduct civil-military and humanitarian operations to help where able and use force as needed. In this same scenario

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military forces must be flexible, ready to act, and easy to support. ... [They] must have the ability to shift rapidly from humanitarian support into combat against unconventional mercenary forces or against a major national power, then transition into peacekeeping operations. A crucial contributor to success is the ability to pack up and move rapidly as situations evolve.⁵⁸

Finally in the 2015 scenario, forces “must shift rapidly from one theater to another.”⁵⁹ With the single exception, each *Alternate Future* required that the US military move its forces quickly in response to events in the world, that those forces minimize their footprints in the operating area, and that they be prepared to conduct a variety of missions across the full spectrum of conflict. Mobility is vital to meeting all of these requirements.

Within *AF2025*, other subordinate research efforts were conducted, including *Airlift 2025* and *Logistics in 2025*. The writers of *Airlift 2025* state that “the availability of overseas bases will continue to decline, thus necessitating long unrefueled ranges, [and] limited materiel on the

ground.”⁶⁰ They go on to state that “a combination of large airships and both powered and unpowered unmanned aerial vehicle (UAV) delivery platforms appear to provide the greatest utility.”⁶¹ Finally, they conclude, “Although the airship is not as fast as modern jet aircraft, its high-cargo capacity (both in weight and volume) allows the delivery of more materiel to the battlefield sooner than a much larger and more expensive fleet of jet aircraft, ultimately supporting the war fighter sooner than today’s air mobility system.”⁶² According to *Logistics in 2025*, “Airlift is the major constraint in meeting current deployment objectives.”⁶³ It is apparent that the writers of *AF2025* understood the importance of mobility to the nation’s interests.

Mission	Capability Gap Theme
Noncombatant Evacuation	Austere Access & Speed
Eliminate WMD	Austere Access & Speed; Seabasing
Peace Enforcement	Mounted Vertical Maneuver; Seabasing
Joint Forcible Entry	Austere Access & Speed ; Mounted Vertical Maneuver
Support to Counter Insurgency	Mounted Vertical Maneuver
Noncombatant Evacuation	Austere Access & Speed
Humanitarian Assistance	Austere Access & Speed
Support to Counter Insurgency	Seabasing

Figure 14: Summary of FDDA Vignettes

Shortly after becoming Commander, USTRANSCOM, General Duncan McNabb established the Future Deployment and Distribution Assessment (FDDA), a “perennial research and analysis effort – conducted in two phases – intended to assess and catalog needed deployment and distribution capabilities and technologies of interest in the extended planning period and beyond (2017+).”⁶⁴ FDDA participants are drawn from all four services, from all COCOM staffs, and from numerous other organizations who interact with and support US mobility forces. A Lockheed Martin HA and the *Aeroscraft* are two of sixteen different “far-term technologies” that have been examined by the FDDA.⁶⁵

The FDDA created eight vignettes in order to assess the utility of the sixteen technologies in supporting a wide range of military operations. They are summarized in Figure 14.⁶⁶ Five of the sixteen technologies were judged as suitable to support all eight missions; three, including the HA and the *Aeroscraft*, were judged as suitable to support seven of eight missions. The author concludes that of all technologies examined, only one is more mature than the HA.

In February 2010, Joint Forces Command published *The Joint Operating Environment 2010 (JOE)*, a study aimed at describing the operational environment that our military is likely to encounter over the next two decades. The *JOE* makes a number of observations regarding force structure and disposition in the coming decades. Regarding the stationing of American forces,

The United States has conducted a global repositioning effort, removing forces from forward basing and garrisoning much of its military force structure at home. Simultaneously, the Joint Force has found itself in near-constant conflict abroad, and now forces based at home find themselves in heavy rotation, projecting forward ... around the world. ... During this time, our forces may be located significant distances from a future fight. Thus, the Joint Force will be challenged to maintain both a deterrent posture and the capacity and capability to be forward engaged around the world.⁶⁷

Regarding the nature of warfare in the coming decades,

Joint Force commanders and their planners must factor two important constraints into their calculations: logistics and access. The majority of America's military forces will find themselves largely based in North America. Thus, the first set of problems involved in the commitment of U.S. forces will be logistical. The tyranny of distance will always influence the conduct of America's wars, and joint forces will confront the problems associated with moving forces over great distances and then supplying them with fuel, munitions, repair parts, and sustenance. ... Failure to keep joint forces who are engaged in combat supplied could lead to disaster, not just un-stocked shelves.⁶⁸

Recognizing these truths is valuable, but a failure to plan for them will eliminate any initial value gained from their recognition. Improving strategic lift of American forces will assist in overcoming the challenges recognized by the *JOE*.

In August 2010, the Army published *The United States Army Operating Concept: 2016-2028 (AOC)* that “describes the employment of forces to guide Army force development and identifies capabilities required for future success. The ideas … are central to the way the future Army will fight and win and guide the integration of Army forces with a wide array of domestic and international partners.”⁶⁹ The Army established some basic assumptions in the writing of the AOC regarding future conflicts. Among the ones pertinent to this discussion, three stand out:

- Adversaries will be able to achieve tactical, operational, and strategic surprise based on rapid application of available and emerging technologies in both manned and unmanned systems.
- U.S. forces will face increasing anti-access and area denial challenges due to strategic preclusion, operational denial, and tactical overmatch.
- U.S. forces will have limited ability to overcome anti-access and area denial capabilities, deploy into austere locations, and sustain operations in immature theaters.⁷⁰

The AOC lists required capability categories for the future Army. One of those categories is *Sustainment*, partially defined by the following:

Deploy the force and overcome anti-access capabilities. Future Army forces require the capability to mobilize, deploy, receive, stage, move, and integrate people, supplies, equipment, and units into an area of operations using advanced technology to avoid and/or mitigate enemy employment of strategic preclusion, operational exclusion, anti-access and area denial capabilities and to ensure freedom of action.⁷¹

Furthermore, the AOC defines 46 required capabilities that the future Army must possess, the first two of which relate to *Movement* and *Maneuver* while the final two relate to *Sustainment*:

- Future Army forces require the capability to conduct joint vertical maneuver with mounted and dismounted forces into austere environments and unimproved entry locations while conducting combined arms operations to exploit positional advantage, put large areas at risk for the enemy, shorten the duration of battle, present multiple dilemmas to the enemy, and contribute to the more rapid disintegration of the enemy force.⁷²

- Future Army forces require the capability to rapidly transition between operations, shift between missions and engagements at distances from standoff range to close combat, and adjustment of geographical sectors while conducting full-spectrum operations to seize, retain, and exploit the initiative.⁷³
- Future Army forces require the capability to rapidly deploy and sustain forces, equipment, and materiel to multiple, widely dispersed locations down to point of employment without reliance on improved aerial and sea ports of debarkation to mitigate anti-access challenges and allow the joint force to seize, retain, and exploit the initiative.⁷⁴
- Future Army forces require the capability to deploy forces with a fight off the ramp configuration which requires minimal RSOI and reconfiguration prior to employment in austere and complex geographical environments to allow the joint force to seize, retain, and exploit the initiative.⁷⁵

The Army, historically the main beneficiary of strategic mobility, views its ability to enter into an area of operations and commence the fight as vitally important. As well, the Army postulates that it will increasingly have to fight in austere locations immediately upon debarkation. Each of the above capabilities would benefit from the existence of HL/HS HA capability.

Most recently, General John Shaud, USAF, (Ret) summarized the findings of the *Air Force Strategy Study 2020-2030* in an article in *Strategic Studies Quarterly*. He writes

The United States faces humanitarian disasters, resource conflicts, terrorism, small-scale conventional conflicts, insurgencies, and the potential for peer conflicts. Flexible power projection is certain to prove critical to American success in these conflicts. In a global security environment marked by the proliferation of advanced anti-access and area denial (A2/AD) systems, American forces will find it increasingly difficult to establish secure bases within striking distance of adversaries. This will increase the demand for long-range power projection options. Successful power projection is undoubtedly the most critical capability the Air Force will provide combatant commanders and the nation.⁷⁶

The environment that he describes matches closely with the findings of the *POND* and *Air Force 2025* studies.

Summary

The unique combination of operating characteristics that HA provide to the military would help alleviate current shortfalls in military mobility, shortfalls that have been noted at least since Operation DESERT STORM. At the same time, trends that are widely recognized in planning efforts across the military that will adversely affect operations in the coming decades might easily be mitigated through the development and employment of HA.

The following chapter proposes a HA capability to be fielded in 2035. Following that, it discusses the technological and other hurdles that will need to be overcome to realize that capability. In light of recent mobility assessments and the results of studies examining the strategic environment, it is a capability that should be pursued.

V: Proposed Heavy Lift / High Speed Hybrid Aircraft

Although now dated and overtaken by a range of technology developments, the *SkyCat 1000* study contains the most detailed technical description of a large non-rigid HA to be used for strategic lift available. Written approximately a decade ago, its authors concluded that an aircraft with a 500-ton lift capacity could have been constructed at the time that met all performance goals. The only technological hurdle to be overcome prior to construction of a 1000-ton capacity vehicle was the development of high strength fabrics for its lifting envelope. Technological advances in the ensuing decade have eliminated that hurdle.

Nominal Capability

Figure 15 proposes a nominal capability for the *Blue Horizons Airlifter* and compares it to the *SkyCat 1000*. As this effort examines an aircraft for the 2035 timeframe, increases in various characteristics are offered above those of the *SkyCat*. The author believes that these

improvements are conservative; they are offered not to demonstrate specific magnitudes of improvement but to demonstrate those areas where operational improvements can be made.

	SkyCat 1000	Blue Horizons Airlifter
Payload	1,100 tons	1,300 tons
Nominal Range	4,000 nautical miles	6,000 nautical miles
Speed	100 knots (115 mph)	115 knots (132 mph)
Nominal Operating Altitude	9,000 ft (fully loaded)	10,000 ft (fully loaded)

Figure 15: Blue Horizons Airlifter Capability

Technology Hurdles and Technical Challenges

The successful development of the *Blue Horizons Airlifter* will require a number of issues to be overcome. Some are technological, necessitating the creation of new or pushing the boundaries of current technology; others are of a technical nature, the integration and engineering know-how to accomplish a given task with technology already in existence. These issues include the development of lightweight, high-strength fabrics for use in lifting envelopes as well as the fabrication processes used to construct them, further advancements in lightweight structural components, aerodynamic modeling to understand and optimize the flight characteristics of these vehicles, buoyancy control systems to ensure that the onload/offload of vast amounts of cargo does not adversely affect flight characteristics, and advanced avionics and flight control systems.

The most commonly cited technology that needs to be improved prior to the employment of non-rigid HA is the development of lightweight, tear-resistant, high-strength fabrics for the construction of the lifting envelope. This is no longer the case. DARPA's ISIS program has taken an innovative approach for the construction of its lifting body—relying on technology

developed for a very different customer: world class sail boats. Cubic Tech Corporation, a subsidiary of North Sails, has been fabricating sails for America's Cup yachts for 20 years; their flexible laminate materials will carry ISIS into the stratosphere with characteristics that far surpass what was available even ten years ago.^{77,78} A company with a longer history serving the military LTA segment is Warwick Mills, currently partnered with Northrop Grumman in the construction of the LEMV; they have been supplying materials to the US military since World War II. TCOM LP is a third company that specializes in construction and design of LTA vehicle envelopes; Lockheed Martin contracted with them for construction of *P-791*. These companies possess the ability to manufacture high strength fabrics for use in non-rigid HA.

While fabrication of these materials is not the technological hurdle it once was, their large scale manufacture remains a technical challenge. The technologies to cut, seam, and bond huge swaths of material, including the machinery to do so and the facilities in which to work, need to be optimized for continuous production of these vehicles. Manufacturing and then assembling the materials for a single unit, whether an America's Cup class sailboat or the Air Force's ISIS platform, relies on artisan craftsmanship, in that it involves handcrafted, labor-intensive processes that cannot at this time easily be "industrialized." These processes will have to be in order to cost-effectively produce large numbers of HA hulls.

The greatest challenge facing designers of HA is that of buoyancy compensation as described in Chapter Two. It is not a trivial problem to transport several hundred tons of cargo in a vehicle that relies in large part on aerostatic lift and then offload that cargo while maintaining positive control of the aircraft. There are several methods to overcome this challenge that *might* work, and each of the major developers of HA have proprietary solutions. In some cases, these solutions are technically immature or of a nature to raise the concerns of

possible operators. Regardless, they must be engineered, optimized, and tested on a scale equivalent to the cargo capacities required.

An issue that is both a technological hurdle and a technical challenge is the further development of lightweight, high-strength structural materials used in the construction of the aircraft itself. The operational considerations of maximum altitude, maximum range, and cargo capacity are all positively affected by lightweight construction. Because the total weight of the “system” includes the aircraft itself, its cargo, and its fuel, the ability to minimize the weight of one of these theoretically allows increasing the weight of the others for a given “system.” Minimizing the weight of the aircraft allows greater operational flexibility for the warfighter and/or allows planners to maximize any one of the operational considerations above.

Likewise, minimizing fuel requirements accomplishes the same. Those advancements that reduce onboard power requirements are beneficial, whether high efficiency lighting or computing, innovative cargo management equipment, or advanced systems integration. Attacking the power problem from the other direction, the addition of photovoltaic (PV) cells to the upper surfaces of the HA reduces fuel requirements. The continued development of lightweight, high efficiency PV technology such as thin-film, flexible coatings will serve as a key enabler for the *Blue Horizons Airlifter*.

Perhaps more a computational challenge than technical, aerodynamic modeling is required during the design of massive HA in order to understand and optimize the flight characteristics of these vehicles. Modeling to ensure the most efficient hull form will reduce drag and pay dividends in terms of fuel requirements. Modeling across the full range of operations, from close-to-ground low speed taxiing to high speed transit at altitude and everywhere between will be necessary. An understanding of the impact of wind on the lifting

envelope, especially during slow-speed operations is vital to the safe employment of HA. This data will be crucial to the development of flight software and fly-by-wire systems to reduce the workload of the pilot in operating multiple control surfaces and propulsion units.

Whether of a technological or technical flavor, numerous challenges will have to be met and overcome in the development of HA. Their sheer size and the fact that airships have not enjoyed widespread use in fifty years ensures that forgotten lessons will have to be remembered, new lessons will have to be discovered, and all lessons will have to be learned. This is not to say that HA should not be developed. On the contrary, their advantages, in terms of fuel savings, expanded operations, and cargo capacity, demand that this capability be developed.

Threats and Challenges

The development and employment of HA for widespread use brings with it a host of issues. In many ways, the least of these are technological and technical. The following are other challenges that must be overcome if HA are to be adopted by the military.

Perhaps the most serious threat to the use of HA is the persistent belief that, in the words of former Air Force Chief of Staff General Jumper, “They’re not cool.”⁷⁹ As long as this attitude persists in the military, HA will not be used to their full potential. It is not surprising that the Army, more concerned with properly supporting its troops on the ground than on image or dogmatic constraints, was the first to purchase this type of aircraft. The concept has appeared in official Air Force documents since at least 1996, and perhaps earlier. The Navy, as well, has been aware of the concept for as long. In both cases, institutional bias has prevented either from taking the first step. In meetings with senior military personnel regarding the employment of HA in a wide range of mission areas, certain flag officers have been impressed with and endorsed the

use of this new type of aircraft; others, however, have been dismissive toward the idea, going so far as to state that their particular service “has no need for that capability”.⁸⁰

Beyond the bias against HA due to their “coolness” is the risk that their introduction might pose to many existing systems—systems supported by entrenched bureaucracies who hold great sway in the acquisitions process. The following section lists possible other uses for HA. Each suggestion could eliminate or greatly curtail funding for a current system; the supporters of those systems would do, and have done, everything possible to prevent the introduction of HA.

Stemming in part from the first challenge is the issue of ownership. Which of the services will assume control of a hybrid heavy lift aircraft? In terms of strategic lift, the case could convincingly be made in support of either the Navy or the Air Force, as the *Blue Horizons Airlifter* shares characteristics of both aircraft and ships. Likewise, tactical airlift provided by smaller HA could be owned by the Air Force or the Army.

A possible threat to the future acceptance of HA is the possibility that the Army’s LEMV program fails. When LEMV is fielded, it will be the largest and most visible HA flown to date; its success will do much to demonstrate the viability and potential uses of the concept. Any problem with the program, whether on the part of Northrop Grumman, the US Army, or circumstances beyond the control of either and perhaps having nothing to do with the fact that it is a hybrid, will be used by detractors and naysayers. As a new program, LEMV is extremely ambitious, with an 18-month schedule from contract to flight, and while it is progressing well, fabrication problems, cost overruns, and the dangers inherent in any new flight testing regime may lead to disappointment. Although the author hopes that no issues arise, the possibility must be considered.

The current state of the airship industry is a challenge as well. Currently, there are only two companies who have built and flown HA. The first is Hybrid Air Vehicles (HAV), direct descendent of Advanced Technologies Group (ATG), who built and flew the *SkyKitten* technology demonstrator in 2001. Northrop Grumman has contracted with HAV for the development of its LEMV. The second is Lockheed Martin with *P-791*. Worldwide Aeros Corporation, although having conducted work on various hybrid subsystems, has yet to build a functioning HA. It is, however, a LTA vehicle developer and manufacturer that has built many non-rigid airships and sold them commercially throughout the world. Several other commercial interests exist who are marketing HA, however, there is no proof that any of these other concerns possess the capability to build or operate an aircraft at this time.

Other Uses for Hybrid Aircraft

The advantages of HA have already been discussed: Inexpensive airborne long duration persistence, massive cargo capacity in terms of tonnage and oversized loads, and ergonomic improvements over traditional modern aircraft. While heavy lift is one possible mission area, there are numerous others that would benefit from a HA's advantages.

The recent crises as a result of the Japanese earthquake and resultant tsunami highlight a non-military mission for heavy lift aircraft—humanitarian relief. Currently, helicopters are being used by the Japanese and US militaries and other organizations to conduct search and rescue, deliver relief supplies, and conduct airborne radiation monitoring. Eventually, aircraft will be used in debris removal and rebuilding efforts. HA support of these operations would decrease fuel costs, increase cargo capacity, and allow the helicopters currently being used to concentrate their efforts elsewhere; in addition to bringing in relief supplies, HA could assist with the evacuation of large numbers of stricken civilians. The Senior Logistics Officer for the

United Nations' World Food Program reported that airships would be extremely valuable conducting emergency relief operations in place of their current fleet of aging conventional aircraft that are expensive to fuel and maintain.⁸¹

Medium altitude persistent ISR will become the first military use for HA once the LEMV becomes operational. While it provides battlespace awareness for soldiers on the ground, other uses for the capability exist, and as HA become larger and able to carry greater amounts of payload for longer periods of time, this capability will improve. Current ISR platforms, whether airborne or space-based, manned or unmanned, are limited by the payload that they can carry. This is not a concern on HA; *every* type of sensor in existence today could be lofted on a single aircraft. Very large aperture radars, larger than possible on traditional aircraft, could significantly improve ISR. Homeland security, border patrol, port and installation security, and counternarcotics are all missions that could be conducted more cheaply and effectively.

HA are perfectly suited to carry out the roles that their LTA predecessors performed during both World Wars—maritime patrol and antisubmarine warfare. Interestingly, the US Navy retired the last of its blimps in 1962, the same year that the P-3 Orion entered service. The P-8 Poseidon, the replacement for the P-3, is currently under development as is the Broad Area Maritime Surveillance (BAMS), a Global Hawk optimized for maritime patrol. This mission could be more effectively and cheaply performed by HA.

Airborne battle management and command and control missions, which typically do not rely on speed, but do rely on persistence and a very sophisticated payload set, could be flown more cheaply on HA. Aircraft such as the E-2 Hawkeye, E-3 Sentry, E-6 Mercury, and E-8 Joint STARS burn a significant amount of fuel to allow their persistence; this would not be necessary with a hybrid. In particular, the E-6 in its TACAMO role flying over the continental US with a

trailing wire antenna deployed could be replaced by a hybrid able to stay aloft for much longer periods of time while providing greater capabilities.

Currently, various types of high value (naval) units are escorted by helicopter when they enter or leave port. A HA with its lower operating costs and vastly increased payloads could perform the same mission at a fraction of the cost with improved capabilities. By the same token, when US fleets pull into foreign ports, a helicopter patrol is conducted of that port and oftentimes a continuous patrol is maintained for the duration of that port visit as force protection for those assets. Such a mission would again be better and more efficiently conducted by HA.

Another ISR-type mission that could be performed by HA is environmental monitoring. Increasingly, the US military spends money on conducting environmental impact studies related to the construction and continued operation of weapons ranges and testing grounds, both land-based and maritime. These studies often attempt to determine the impact of operations on various species of wildlife, including habitats, life cycles, and migratory patterns. The military also spends money combating litigation brought by various environmental non-governmental organizations regarding the same. At present, the military, including the Coast Guard, uses helicopters to conduct or assist in the conduct of these studies, which are expensive when factoring fuel costs and inhibit actual military operations by “wasting” airframe flight hours. HA used to monitor specific areas or species over prolonged period of time could gather data cheaply and much more effectively than helicopters can today.

While lift and ISR are probably the first two general mission areas that could be undertaken by HA, they could also be weaponized. HA may be the perfect airborne laser platform, whether the Advanced Tactical Laser as carried on a C-130 or the larger YAL-1 Airborne Laser carried aboard a Boeing 747-400F. Much of the development cost of each of

these programs involved the size and weight reduction required to fit the laser into an existing aircraft. Eliminating this need by carrying the laser in an aircraft with greater payload volume and weight capacity would greatly simplify the design and manufacture of these weapons.

HA properly outfitted with weapons could serve as a complement to the AC-130 in a gunship capacity where long dwell time, massive cargo capacity, and slower speed are advantages. Effectively silent from the ground with very low radar cross sections, HA would be extremely useful as a SPECWAR asset. A HA could also be used as a Precision Munitions Platform, similar to the Navy's SSGN, a submarine capable of almost unlimited dwell time carrying up to 154 Tomahawk missiles. An "arsenal airship" floating near "hotspots" or the scene of military operations would allow the COCOM greater flexibility in planning operations.

The utility of HA in many of these mission areas should be evident, however, several do assume that air superiority has been achieved, because, although "survivable," they would not survive long in a high-threat environment. It is because of this reality that HA would not wholesale replace the platforms mentioned in the preceding paragraphs but complement them by providing similar, though by some measures superior, capabilities more cheaply.

Summary

Building upon previous design efforts, HA with capabilities similar to the *Blue Horizons Airlifter* could be designed and built by 2035. While there exists a range of technical, technological, and other issues that need to be resolved prior, success would create a new class of aircraft, the fundamentals of which are very attractive for military and civilian use. Strategic mobility is the focus of this research effort, but efficient and persistent airborne operations are compelling enablers of numerous other missions. The next chapter will present the author's recommendations to the DOD to achieve this capability.

Conclusion

Critics dismiss airships out of hand because they are not capable of flying over medium altitude threats as airplanes can. The utility of airships is more readily apparent, however, if one considers them not as a replacement for the C-17 but as a vehicle with the payload of a small ship that flies several thousand feet over the ocean at 100 knots, and can then proceed inland as far as the threat will permit, and land in a large field. They would constitute a valuable third mode of strategic transportation for USTRANSCOM with speed much better than a ship and economics much better than an airplane.⁸²

Recommendations

The first step in fielding this capability, the initial employment of HA, has already been initiated. The US Army's LEMV, although not specifically designed to conduct lift, will be the first military HA to be flown in an operational environment. During its construction and testing, Northrop Grumman will gain valuable experience in its handling and flight characteristics. This will be experience already achieved by Lockheed Martin during the construction of its *P-791* technology demonstrator in 2006. The first recommendation is to contract each company to conduct the engineering analysis and data collection to optimize these current designs for lift. Neither aircraft was designed for this purpose, but their nascent capabilities will help to determine future development paths. DOD should also contract Worldwide Aeros Corporation to construct a small-scale technology demonstrator *Aeroscraft* in order to test the feasibility of their proprietary technology.

The purpose in pursuing three separate development paths, each led by a different contractor, may seem extravagant, especially in light of current fiscal conditions. However, HA form a fourth and new type of aircraft, the other three being lighter-than-air, fixed-wing, and rotary-wing, that may revolutionize numerous airborne missions. Having multiple companies with experience in constructing and operating these vehicles will benefit the United States by

ensuring that no one contractor has a monopoly on the technology and that the loss of a single contractor will not end development of these vehicles. As well, the point must be made that one type of HA is not a recipe for all. A Predator UAV is different from an A-10 is different from a C-130—they are all fixed-wing aircraft, can carry payload, and can be weaponized. However, their designs are optimized to a narrower mission set. Likewise, at some point in the future, there may be a number of different hybrid approaches each supporting different mission sets, and each operated by the DOD.

The second recommendation is to contract for the construction of a payload demonstrator capable of meeting some increment of the operational capabilities proposed for the *Blue Horizons Airlifter* in Chapter Five, perhaps carrying a payload of 20-30 tons, to a nominal range of 750 nautical miles, at cruise speed of 75 knots and an altitude of 7,500 feet. In the best case, at least two competing designs would be constructed. Following in the footsteps of DARPA's WALRUS program, this might entail one rigid and one non-rigid design, however, the decision of which two contractors to be chosen would have to rely upon the results of their efforts following the actions of the first recommendation. It is quite possible that there exists military utility for a HA with these capabilities and, if so, production could commence on some number of hulls following demonstrated operations. If successful, subsequent classes of HA could be designed for other mission areas and/or expanded to handle larger and larger mobility payloads, eventually culminating in the *Blue Horizons Airlifter* itself.

The final recommendation is for DOD to focus research and development funding in those technology areas that will help to improve future HA capability, most of which are generic and beneficial regardless of their utility to this concept: lightweight structural materials, advanced PV and battery technologies, computer aerodynamic modeling, high efficiency

computing, innovative cargo management equipment, and advanced systems integration. These technologies are important and should be pursued regardless of one's opinion of HA.

Last Words

The writers of *Airlift 2025* concluded their report with the following:

For the concepts proposed in this paper to become a reality, two events must occur. First, the ever widening gap between airlift requirements and airlift capability must be acknowledged. Advanced warfighting systems are of little utility if the warrior is unable to sustain, or even join, the fight. Second, emphasis must be placed on those systems that best solve the problems future conflicts present. Adherence to the adaptation of archaic systems and ideas to the problems of the future (as the French did before World War II) only serve to delay the inevitable: the catastrophic failure of a system in the face of requirements it was never capable of addressing.⁸³

While those words were written in 1996, they remain applicable today. More recently, the *Joint Operating Environment 2010* states that:

The next quarter century will challenge U.S. joint forces with threats and opportunities ranging from regular and irregular wars in remote lands, to relief and reconstruction in crisis zones, to cooperative engagement in the global commons. ... U.S. military forces will be continually engaged in some dynamic combination of combat, security, engagement, and relief and reconstruction. ... In this environment, the presence, reach, and capability of U.S. military forces, working with like-minded partners, will continue to be called upon to protect our national interests.⁸⁴

The ability of the US military to move massive amounts of cargo quickly and cheaply will affect its ability to do all of these things; a Heavy Lift, High Speed Hybrid Aircraft Transport, a *Blue Horizons Airlifter*, offers a revolutionary capability to accomplish this. The US military should invest in these technologies today.

Appendix A: DOTMLPF Issues Highlighted by the POND Study

The POND Experimentation campaign considered the following issues during the evaluation process. It is important to note that changes required to DOTMLPF to fulfill the prescribed requirement will not render the required solution. Instead, these changes must be combined with material solutions to be effective.

Doctrine

- Doctrine for phased arrival of SBCT force modules at point of need
- Examine SBCT organization to reduce lift requirement
- Change how SBCT is organized to provide airfield control
- RO-RO capable requirement must be addressed
- Stryker Operations:
 - Ammo
 - Fuel levels
 - Crew onboard
 - RO-RO and start shooting
 - Standardized TO&Es
 - Immediately employable without full basic load
 - Training
 - Spin-up
 - Paradigm shift
 - “Air assault mentality” for mounted units
 - Employ 3-5 days from now
 - Marine Expeditionary Force model, arrive ready to fight
- RSOI challenges: Scenario specific. More research is required in this area. The primary issue is whether to conduct RSOI before the last stage or arrive 25 km out and constitute the force.
- Doctrine for phased arrival of ready to employ force modules at point of need
- Implications for strategic movement directly to point of need (TRANSCOM vs. Theater DDOC)

Organization

- LTA represents a fundamental organizational shift
- Should have single deployment/distribution process owner (TRANSCOM) with responsibility for entire movement
- Task Organization

- Deployment TTPs
- Mission Based/Commander's Decision
- Slice/Incremental Build-Up
- Breakdown of unit transportation – what “slices” are delivered when
- What is the smallest operational/self-sufficient unit size? What is the minimum “chunk” to be delivered as a coherent/capable unit?
- Deploying unit needs to be able to provide airfield control in austere environments (CRG vs. AFSOC)

Training

- Training for hybrid landing sites and all other hybrid support functions
- Significant training costs/requirements with any new platform

Personnel

- Introduction of a new system (new tilt-rotor or hybrid) requires a new group of people with new skill sets (example is UAV) that require training, career path, etc.
- Hybrid – may require remote manning
- Hybrid airships may be manned like a traditional aircraft with long flight durations (2 Pilots/Navigators, etc.) or like a Navy ship, i.e. captain and crew

Facilities

- New system will require significant support infrastructure
- Potential hangar facilities for large Hybrids
- Berthing and mess accommodations for multi-day transit

Policy

- Policy Changes allowing transport of fully loaded combat vehicles fuel/ammo on combat platforms
- HAZMAT/Safety/Federal Regulations that restrict/constrain movement, i.e. Current Fuel Policy: $\frac{1}{2}$ tank of fuel in vehicle/no bulk fuel
- RFF process is too slow. Change policy to streamline the RFF process (CENTCOM managing 1-2 yrs out; 1-yr out requires too many exceptions to policy and changes in TPFDD)

Role of commercial enterprise (Contracting Non-Gov Owned Lift)

- Training
- Impacts of working with Civilians
- Defined crew day for contracted lift
- Define Contractual Responsiveness

Command

- Plan to transition command forward from command rear
- JTF (or equiv) command structure required to provide direction
- Brigade CC will perform analysis to tailor force structure/package
- BCT is ready to employ: majority of integration conducted en route
- Providing joint support to ground unit

Control

- ADVON/reception team for basic C2 and reception capability
- Task organize as early as possible prior to deployment

Communications

- BCT has full comms prior to deployment
- Capability to have fly-away comms
- Secure beyond line-of-sight comms and COP for ITV and C2 while transiting

Integration

- Integration with higher command prior to deployment
- Final operational integration at the point of need
- Attachments/host nation/interagency

Appendix B: POND Study Results, Insights, and Recommendations

Results

The POND Experimentation campaign validated that the current lift platforms available to a COCOM Commander cannot meet the deployment requirements outlined in the requirements statement for the experimentation campaign. Areas of improvement to deployment timeframes were identified within the DOTMLPF review. However, these improvements did not result in the ability of a joint force commander to deploy a ready to employ force to a point of need to every location within the COCOM AOR in three to five days without reliance on host nation infrastructure.

As outlined in the Design and Control Plan, Attachment A, the experiment modeled and discussed the SSSP concept of employment to identify improvements that could be achieved and looked at the ability of the EUCOM commander to deploy a significant force to a common trouble area in the AOR. The modeling process used, and results of the runs, are outlined in the Attachments entitled; Airship Optimization and Energy Consideration Scenario, and Model Tools and Approach, Attachments D and E. The experiment determined that the only platform that had the capability to meet the requirements outlined in the problem statement was a hybrid airship capable of lifting at least 200 short tons. Other platforms, sea and air, did not have the range, lift capabilities, or required host nation support to move a unit to the point of need.

Based on suggestions raised in the TTE, the team considered an alternative concept of employment for the experiment similar to the Haiti response but on a larger scale; deploying a heavy engineering capability, in the form of a Navy Mobile Construction Battalion (3,000 tons) to a point of need over 2,500 miles away. The goal of this deployment was to respond to a natural disaster where there was insufficient infrastructure to support traditional deployment

platforms. The team concluded that hybrid airship technology would enable the entire battalion to deploy to the location within four days, without requiring infrastructure support. This contrasts with a similar movement of a Navy Mobile Construction unit (690 tons), far smaller than a full Battalion, to Haiti which took over thirty days and required the rehabilitation of the port area in order to offload heavy equipment.

Additionally, airship technology significantly reduces the costs of deployment. As the fully burdened cost of fuel becomes a key consideration in future platforms, the fuel efficiency of airship technology becomes a key consideration. A study by the RAND Corporation of hybrid technology concluded that a hybrid airship would use approximately 80 percent less fuel than C-17 platforms performing the same mission. The Air Force Global Mobility (GLOMO) Exercise 10 determined that the combination of hybrid airships with C-17's and surface vessels would have resulted in fuel savings in the billions of dollars for a single 30 day deployment period. Applying these principles to Operation ENDURING FREEDOM, the use of airship technology to support the rotation of assets results in a 50 percent reduction in deployment time and a 30 percent reduction in fuel costs. One research paper proclaims: "*Economic indicators reveal 60% reduction in cost over fixed-wing aircraft in total cost per ton-mile.*" In a more recent RAND Study, the Cost Per Ton Mile of a hybrid airship was \$0 .22, while a C-17 performing the same mission was \$1.2017. This represents approximately a 80% reduction in costs per ton mile using hybrid technology for the scenarios that were tested against.

Insights

While the experiment did not address logistic support, operational maneuver, anti-access, radar/jamming, or gunship scenarios, the effort did provide some insights into the potential for hybrid airships to contribute to these missions.

1. One significant finding from the wars in Iraq and Afghanistan has been the cost in lives and resources in maintaining ground lines of communication. Hybrid airships of between 50 and 200 tons could replace many of these LOCs with greater speed and effectiveness and at a potentially significant saving in lives and resources.
2. The Army has been working on a concept for moving combat forces at operational distances around a modern battlefield. To date the primary focus of this concept has been on large rotary wing aircraft. The potential procurement and operating cost of these aircraft and their relative lack of resilience compared to hybrid aircraft suggest that rotary wing aircraft may not be the best choice for this mission.
3. Many of the scenarios being investigated by DOD force structure analysts involve the challenge of conducting operations in the face of anti-access defenses. Hybrid aircraft offer a potential anti-access solution that could involve the avoidance of anti-access defenses, which are normally located along the coast and around air bases. Forces embarked in hybrid aircraft hold out the potential for avoiding these defenses, landing in undefended areas, and conducting what might be called “inside out” warfare.
4. The large envelope and cargo carrying capability that is characteristic of hybrid aircraft offers the possibility of carrying large radar antennas or high power jamming equipment that could take the place of similar equipment found on fixed wing aircraft.
5. The load carrying capability and the resilience of hybrid aircraft offers the possibility that they could be used to replace AC-130 gunships to carry a variety of air to surface weapons including high energy weapons.

Recommendations

1. Refine the concept of employment. Recommend the Joint Staff J4 join with EUCOM, AFRICOM and TRANSCOM to refine the employment concept to support COCOM operational events, exercises, and humanitarian relief scenarios.

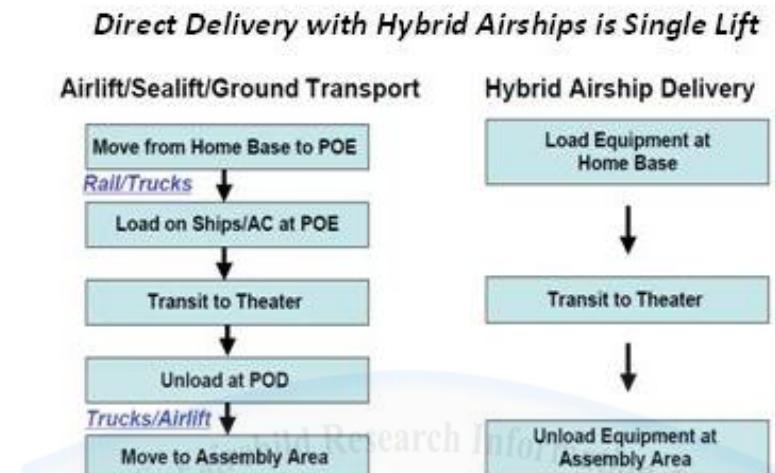


Figure 1

2. Validate fuel savings that can be achieved with airship technology. As the fully burdened cost of fuel becomes an increasingly important operational consideration, reduction in fuel use, the reduction of the requirement to access fuel, and the reduction of fuel costs in the most expensive locations, such as a point of need, takes on increased importance. As demonstrated in the Air Force GLOMO exercise, Attachment D, page AD-7, the fuel savings in a single deployment at a FBCF of \$50.00 would cover the procurement cost of 20 \$200 million airships. Considering the frequency of deployments to remote areas of the world currently supported by both commercial and military lift platforms, the savings generated through airship technology may result in significant reduction in operating costs. The requirement to maintain the ready reserve force RO/RO fleet should also be evaluated. Currently the department has budgeted \$332 million annually to maintain the capability to deploy military forces via sealift.

The majority of these ships require five days prep time prior to leaving their home port, must sail to a port for loading, be loaded, move to theater, unload, and finally assemble material for transfer to final location which could be many miles from the point of debarkation. As illustrated in Figure 1, an airship could carry a similar load directly from its home station to the point of need without the intermodal delays created using sealift.

3. Regardless of the solution adopted, changes in the DOTMLPF-P can render improvements in current deployment timelines. Thus, if a hybrid airship is adopted, develop DCRs to support the optimal use of this technology. Otherwise, develop DCRs to improve movement using traditional vehicles and updated technologies.
4. Investigate the alternative uses of hybrid airships identified in the insights above.
5. Conduct a hybrid airship demonstration using currently available technologies.

¹ Vaeth, 20-21.

² Huett, 5.

³ *The Deltoid Pumpkin Seed* by John McPhee describes the test efforts of the Aereon Corporation.

⁴ Miller, 443-444.

⁵ Ibid., 444.

⁶ Ibid., 445-446.

⁷ Ibid., 448.

⁸ Jane's.

⁹ Ibid.

¹⁰ Huett, 9.

¹¹ Ibid., 10.

¹² Interviews with Mr. Chuck Myers and Mr. Stephen Huett from NAVAIR.

¹³ Huett, 11.

¹⁴ Ibid.

¹⁵ Interviews with Mr. Chuck Myers and Mr. Stephen Huett from NAVAIR.

¹⁶ DARPA, 1.

¹⁷ *Defense Industry Daily*, 04 April 2006.

¹⁸ *Defense Industry Daily*, 30 December 2009.

¹⁹ Grant, 70.

²⁰ Email with Mr. Phil Hunt at Worldwide Aeros.

²¹ Dornheim, 1.

²² Email with Dr. Robert Boyd at Lockheed Martin.

²³ See video at <http://www.youtube.com/watch?v=CKAyJ3zKTus> for Lockheed Martin overview of the P-791.

²⁴ Huett, 15.

²⁵ Ibid., 16.

²⁶ Mahony.

²⁷ Warwick.

²⁸ Ibid.

²⁹ Interview with Dr. Robert Boyd at Lockheed Martin.

³⁰ Gordon, 49.

³¹ *SkyCat1000 Engineering Study*, 144-147.

³² Ibid., 8.

³³ Ibid., 16.

³⁴ Ibid., 15.

³⁵ Ibid., 117.

³⁶ Ibid., 228.

³⁷ Vogt, 9-10.

³⁸ McGuinness, 13-14.

³⁹ Email with Mr. Phil Hunt at Worldwide Aeros.

⁴⁰ Clifton, 1.

⁴¹ Burns, 18.

⁴² Clifton, 14.

⁴³ Eisenhut, 14.

⁴⁴ Ibid.

⁴⁵ *Defense Acquisitions*, Executive Summary.

⁴⁶ Ibid., 20.

⁴⁷ *Moving U.S. Forces*, 52.

⁴⁸ *Moving U.S. Forces*, 52-56.

⁴⁹ Newbegin, 45.

⁵⁰ McGuinness, v.

⁵¹ Ibid., v.

⁵² Ibid., 1-2.

⁵³ Ibid., v.

⁵⁴ Ibid., vi.

⁵⁵ Ibid.

⁵⁶ Ibid., 13.

⁵⁷ Englebrecht, 30.

⁵⁸ Ibid., 91-92.

⁵⁹ Ibid., 105.

⁶⁰ Fellows, vii.

⁶¹ Ibid.

⁶² Ibid., 44.

⁶³ Edgell, vii.

⁶⁴ *Future Deployment and Distribution Assessment*, 9.

⁶⁵ Ibid., 24.

⁶⁶ Ibid., 78.

⁶⁷ US Department of Defense. *The Joint Operating Environment 2010*, 60.

⁶⁸ Ibid., 63.

⁶⁹ TRADOC Pam 525-3-1, 5.

⁷⁰ Ibid., 7.

⁷¹ Ibid., 48.

⁷² Ibid., 51.

⁷³ Ibid., 52.

⁷⁴ Ibid., 54.

⁷⁵ Ibid.

⁷⁶ Schaud and Lowther, 9-10.

⁷⁷ McDaniels, 2.

⁷⁸ Go to <http://www.na.northsails.com/TECHNOLOGY/TechnologyVideos/tid/12595/Default.aspx> to see several videos that highlight their technology. The “How It’s Made” video, a clip from the Science Channel television show of the same name, is particularly informative.

⁷⁹ Grant, 70.

⁸⁰ Interviews with Mr. Chuck Myers and Mr. Stephen Huett from NAVAIR.

⁸¹ Collignon, 26.

⁸² Gordon, 58.

⁸³ Fellows, 59.

⁸⁴ US Department of Defense. *The Joint Operating Environment 2010*, 4.

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